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Table of Contents

Volume 3, Number 4

1997

Executive Summaries

AIR FORCE 2025 OPERATIONAL ANALYSIS

by Jack A. Jackson, Gregory S. Parnell, Brian L. Jones, Lee J. Lehmkuhl, Harry W. Conley and John M. Andrew

The USAF Chief of Staff determined that the long-range planning process within the USAF was broken. To reverse this trend, he initiated a year-long study, Air Force 2025, to generate ideas and concepts on the capabilities the United States will require to possess the dominant air and space forces in the future, to identify new or high-leverage concepts for employing air and space power, and to outline the technologies required to enable the envisioned capabilities. This article outlines the operational analysis, which used Value-Focused Thinking, that supported the Air Force 2025 study.

APPRAISING WARFIGHTING CONCEPTS WITH WARGAMING SIMULATIONS

by Robert M. Chapman

Military operations research professionals use analytical simulations to explore a wide range of issues in the acquisition and policy arenas. Many of these analytical simulations, however, are inappropriate for examining warfighting concepts because of their simplistic treatment of human behavior especially decision processes. In contrast, simulations used in battlestaff training programs are designed to accommodate decision processes. There are, however, significant challenges in using training simulations for systematically examining military issues. This paper presents a methodology for using a training simulation to explore a technology-based warfighting concept. The methodology was developed to support JWFC's participation in the 1996 Defense Science Board Summer Study. Although developed and executed in just under two months, it required a significant commitment of resources. The effort, however, was very productive because it produced a methodology that is different from that used in most analytical simulations-based studies. The methodology used by JWFC blended techniques from training-based wargaming events with those used for analytical experiments. Often people assume there is symmetry between simulation-assisted exercises and analysis if they both use computer models. Such an assumption, which focuses on the tool instead of the task, can lead to flawed methodologies. Understanding the difference, though, can provide a useful tool for military operations research.

CONCEPT EXPLORATION ON THE VIRTUAL BATTLEFIELD

by Gary Q. Coe

1996 Defense Science Board Summer Study on Tactics and Technology for 21st Century Military Superiority addressed the challenge of identifying new analytic tools for concepts evaluation, motivated by the evolving "new world order" that changed missions and environments for future war and the increasing Department of Defense investment in information technology for improving future warfighting capability. In support of this effort, an experiment was designed for evaluating new concepts suggested by the Army After Next and Marine Corps Sea Dragon combat development programs and conducted on a future battlefield. The experiment was conducted at the Institute for Defense Analyses using advanced distributed simulation technology including equipment and personnel virtually interacting with a synthetic battlespace. It was supported by the U.S. Army National Guard and U.S. Marine Corps active duty personnel. The Army Research Institute development human performance criteria, provided observers to evaluate human behavior of the individual combatants, and assisted in data analysis from the experiment.

THE COST EXCHANGE RATIO: A NEW AGGREGATE MEASURE OF COST AND OPERATIONAL EFFECTIVENESS

by Bruce W. Fowler and Pauline P. Cason

Aggregate measures of performance have value to analysts and decision makers alike in comparing alternatives and variations on a common scenario. Traditional aggregate measures have included the Force Exchange and Loss Exchange Ratios. These measures are well defined for single system (homogeneous) scenarios, but re-

quire some aggregation methodology for a multiple system (heterogeneous) scenario. Different methodologies have been advanced to perform this aggregation in a purely operational context. An alternative aggregation methodology is cost of the systems and their ammunition. This permits the formation of a Cost Exchange Ratio which combines operational performance and operational cost to provide an aggregate measure of cost and operational performance. Combining this methodology with an operational aggregation methodology permits definition of a Normed Cost Exchange Ratio which permits comparison of the cost and operational performance of an alternative or variation force to an equivalent single system base force, thus avoiding the difficulty of making cost comparisons across cultures. Together, these two cost ratios provide an aggregate means for assessing cost variation in an operational context, thus facilitating modern acquisition decisions based on such considerations as Cost as an Independent Variable.

AIRBOURNE AND SPACE-BOURNE RECONNAISSANCE FORCE MIXES: A DECISION ANALYSIS APPROACH

by Terry A. Bresnick, Dennis M. Buede, Albert A. Pisani, Leighton L. Smith and Buddy B. Wood

Given the importance of joint reconnaisance to today's operational commanders and increasing reliance on reconnaissance for the future, the Joint Requirements Oversight Council (JROC) recognized in 1995 that it had no means to make force mix decisions in terms of end-to-end platform capability and cost across all components: manned, unmanned, and overhead. To fulfil this need, the JROC created the Reconnaissance Study Group (RSG) and tasked it to develop and implement a process for making timely and informed reconnaissance force mix decisions. This paper describes an innovative decision analysis methodology for determining the composition of promising reconnaissance architectures at various levels of investment for the 2010 time frame. The results of this study were not developed to feed into any JROC decision making process, but to illustrate a methodolgy; nonetheless, the results have been utilized by a number of DOD organizations.

SPECIAL ISSUE ON

MILITARY OPERATIONS RESEARCH METHODS

FOR FUTURE R&D CONCEPT EVALUATION

The Research and Development (R&D) funding decisions made by United States military planners will have a large impact on the technology base the United States (and its allies) will have available to develop future offensive, defensive and information systems. The purpose of these systems is to deter or, when deterrence fails, to win armed conflicts. In addition, terrorist bombs, weapons of mass destruction and cyber warfare threaten our national security. As defense spending has been reduced, less funding has been available for R&D. Therefore, the R&D decisions we make in the next few years will be especially critical.

Limited R&D budgets make it imperative that we analyze the potential operational benefits of future system concepts and select the most promising concepts for R&D. Military operations research offers several techniques to help senior DoD decision makers prioritize future R&D concepts and identify the most promising technologies to pursue.

The purpose of this special issue is to describe military operations research techniques which have been successfully used to evaluate future R&D concepts and to propose improvements to military R&D concept evaluation techniques.

Dr. Gregory S. Parnell
Editor, *Military Operations Research*

Air Force 2025 Operational Analysis

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OR METHODOLOGY: Decision Analysis

APPLICATION AREA: Air & Space Warfare

ABSTRACT

In the fall of 1994, the Air Force Chief of Staff tasked Air University to do a year-long study, **Air Force 2025**, to "generate ideas and concepts on the capabilities the United States will require to possess the dominant air and space forces in the future [, to identify] new or high-leverage concepts for employing air and space power [, and to detail] the technologies required to enable the capabilities envisioned." To support this goal, we conducted an operational analysis using Value-Focused Thinking to identify high-value system concepts and their enabling technologies in a way that was objective, traceable, and robust. We developed the ***Foundations 2025*** value model and identified the system concepts that showed the greatest potential for enhancing future air and space capabilities and the embedded technologies with the highest leverage in making the high-value system concepts a reality. Six alternative futures were identified and a sensitivity analysis was performed to see how sensitive the best systems were to the alternative futures. The ***Foundations 2025*** value model was a significant analysis achievement and has several important future uses.

THE CHALLENGE

If we are going to be relevant in the future, we've got to somehow break free of the evolutionary nature of the planning process.
—Gen Ronald R. Fogleman, CSAF, September 6, 1995

The Chief of Staff of the Air Force, Gen Ronald R. Fogleman, challenged the participants of the **Air Force 2025** (*AF 2025*) study to generate ideas and concepts on the operational capabilities the United States will require to dominate air and space forces in the future (Fogleman, 1994). In response to General Fogleman's tasking, Air University devised a four-phase study process (Figure 1) to stimulate creativity, generate ideas, and evaluate system concepts and technologies.

In the preparation phase, participants were exposed to a wide variety of creative thinking and problem solving concepts. This phase laid the groundwork for the idea generation phase, in which teams developed plausible alternative futures and future system concepts, and identified the enabling technologies for those concepts. During this phase, a worldwide data call produced over 1,000 submissions. In the assimilation phase, the participants were organized into specific teams based on operational exposure. Each operator team focused on a particular area, such as interdiction, information warfare, on-orbit support, etc. After postulating the required capabilities of the future Air Force, as part of the Value Model development, each team developed system concepts and identified technologies from the idea generation phase that could satisfy these future requirements. This phase produced a large number of system concepts that were described in varying levels of detail, provided widely different kinds of operational capabilities, and depended on different levels of advancements in different areas beyond current technology. Clearly, not all of these system concepts could be developed, nor could all of the technologies be aggressively pursued. The study results needed to prioritize the relative importance of both future system concepts and their enabling technologies (Fogleman, 1995).

An operational analysis (OA) was conducted concurrently with the other three phases to provide this prioritization. Its purpose was to evaluate system concepts and the enabling technologies proposed in the white papers. The operational analysis had three objectives:

- assess the potential operational utility of future air and space system concepts,
- identify the high-leverage technologies required by those system concepts, and
- provide an objective, traceable, and robust analysis.

This paper highlights the main results of the operational analysis; detailed documentation is provided in the ***2025*** Operational Analysis Technical Report (Jackson, et al, 1996b).

METHODOLOGY

After considering the advantages and disadvantages of various analytical approaches, the OA team concluded that Value-Focused Thinking (VFT) (Keeney, 1992) offered the best method for meeting the OA objectives (Jackson, et al, 1996a). VFT was particularly suited for structuring the subjective judgments required to evaluate the systems. It also allowed the OA to be completed in the limited time available and, because VFT was used in the **SPACECAST 2020** study (Burk and Parnell, 1996), it was

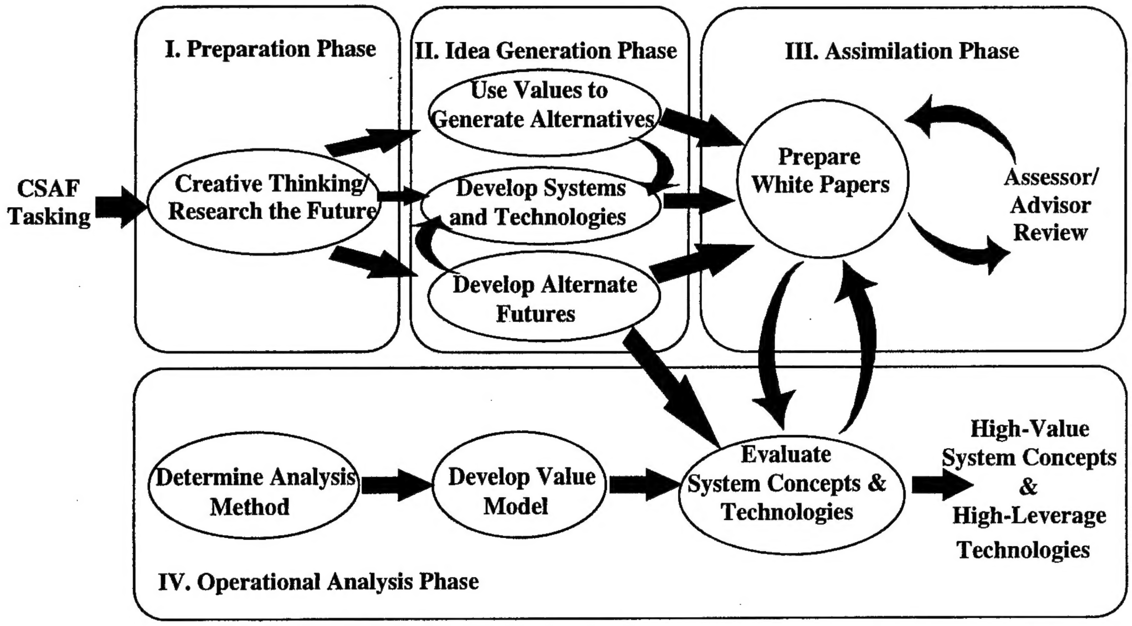

Figure 1. ***AF 2025*** Study Process

well understood and accepted by the Air University senior leadership. In addition, once a value framework was built using VFT, it was very easy to assess systems across several alternate futures. Finally, the VFT methodology enables the OA to be objective, traceable, and robust.

The most important concept in VFT are the decision makers *values*. Keeney (1992) says, "Values are what we care about. [Values] should be the driving force for our decision-making." The decision makers values are the principles used for evaluation.

Value structuring begins by identifying the decision maker's values with a hierarchy of objectives. Top-level objectives describe aspirations that are most important to the decision maker. A value model, called a value tree by some authors, is a branching structure with the most fundamental decision-maker objectives at the top. Keeney (1992) uses the term "fundamental objectives hierarchy," and states, "The higher-level objective is defined by the set of lower-level objectives directly under it in the hierarchy." In other words, the lower-level objectives completely specify their higher-level objective.

Clemen (1991) describes five specific characteristics of a value model.

1. It should be complete, encompassing all important facets of the decision.
2. It should be as small as possible.
3. The force qualities should allow straightforward measurement.
4. Objectives should appear only once in the tree.
5. The decision maker should be able to think about and treat the branches of the tree separately.

Kirkwood (1997) identifies similar criteria for a value model's objectives and subobjectives. He states they should be complete, nonredundant, and independent to meet the mathematical requirements for a linear additive value model.

The OA would contain three important sets of participants (Figure 2). The first group was the Air University operator teams drawn from the top 20% of the field grade ranks in the military services. They performed the role of future decision-makers for this study; some members of this student body will be promoted to the general officer ranks and will make the major acquisition decisions for the study time frame. Next, one of the operator teams, the Alternate Futures team, was tasked with developing a set of plausible future scenarios and histories leading to the year ***AF 2025***. The third group was the Operations Analysis team tasked with performing the analysis for ***AF 2025***, assessing future technical trends, separat-

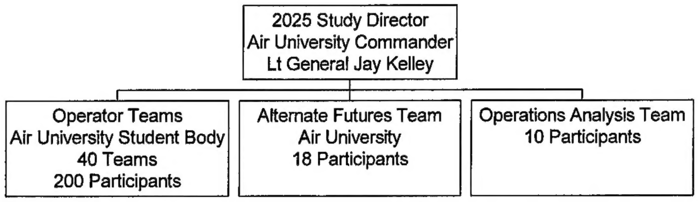

Figure 2. *AF 2025* Team Structure

ing science from science fiction, and evaluating the underlying high leverage technologies.

Figure 3 provides a summary of the operational analysis methodology we developed to meet our three study objectives. Utilizing two main drivers, the Operators and the Technologists, we constructed analytical frameworks for the Operator and Technology groups. The Operators would evaluate the system concepts, from the white papers, based on the systems' operational utility (value). The Technologists would evaluate which technologies contributed to the future systems. We then ranked the systems and technologies and concluded by performing sensitivity analysis.

The Search for the *AF 2025* Value Model

After the OA team selected a VFT approach, the next step was to either select an existing value model framework or develop a new one. Identifying a current framework proved to be a daunting task because of the scope of the study and the focus on the far future. Any potential value model also had to satisfy Clemen's and Kirkwood's criteria.

The OA team initially searched for a national-level strategic document that identified priorities for future air and space forces. We investigated the following sources:

- *A National Security Strategy of Engagement and Enlargement*
- *National Military Strategy of the United States of America* (1995)
- *Defense Planning Guidance*
- Joint Requirements Oversight Council (JROC)/Joint Warfighting Capabilities Assessment (JWCA) categories
- *Global Presence* and *Global Reach, Global Power*
- Common operational objectives of the armed forces (Kent, 1991)
- Draft Air Force Doctrine Document: Air Force Basic Doctrine (1995)
- *Joint Vision 2010* (1996)
- *Cornerstones of Information Warfare* (1995)

None of the frameworks within these documents met the requirements of ***AF 2025*** (Parnell, et al, 1996). Each document was grounded in current doctrinal thinking, and the visionary thinking in the white papers on employment of air and space forces in the far future did not conform to these frameworks. Furthermore, each contains traditional biases focusing on how the Air Force is organized, while ***AF 2025*** addresses the dominant employment of air and space forces in the year 2025 and beyond. The only solution was for the OA team to develop a new framework to capture the visionary thinking that took place during the study. The result was the ***Foundations 2025*** value model (Figure 4). A unique bottom up process was used to develop ***Foundations 2025*** (Parnell, et al, 1996).

To make the terms more meaningful to the military officers, the OA team used the terms *objective*, *functions*, *tasks*, and *subtasks* to designate the tiers in the hierarchy, from highest to lowest, respectively. Functions are the high-level, aggregated tasks that must be accomplished to attain the overarching objective of *air and space dominance.* Three functions for the future Air Force were identified: *awareness*, *reach*, and *power*. The OA team adopted the following definitions for these three functions:

> *Awareness*—knowledge, understanding, or cognizance of some thing or situation through alertness in observing, detecting, and identifying, so as to enable, direct, and communicate an informed decision. *Awareness* is specified by the tasks *detect*, *understand*, and *direct*.
>
> *Reach*—ability to move to expand the range or scope of influence or effect, and to sustain this influence or effect by maintaining and replenishing. To have *reach* requires the ability to *deploy*, *maintain*, and *replenish*.
>
> *Power*—ability to overtly or covertly affect,

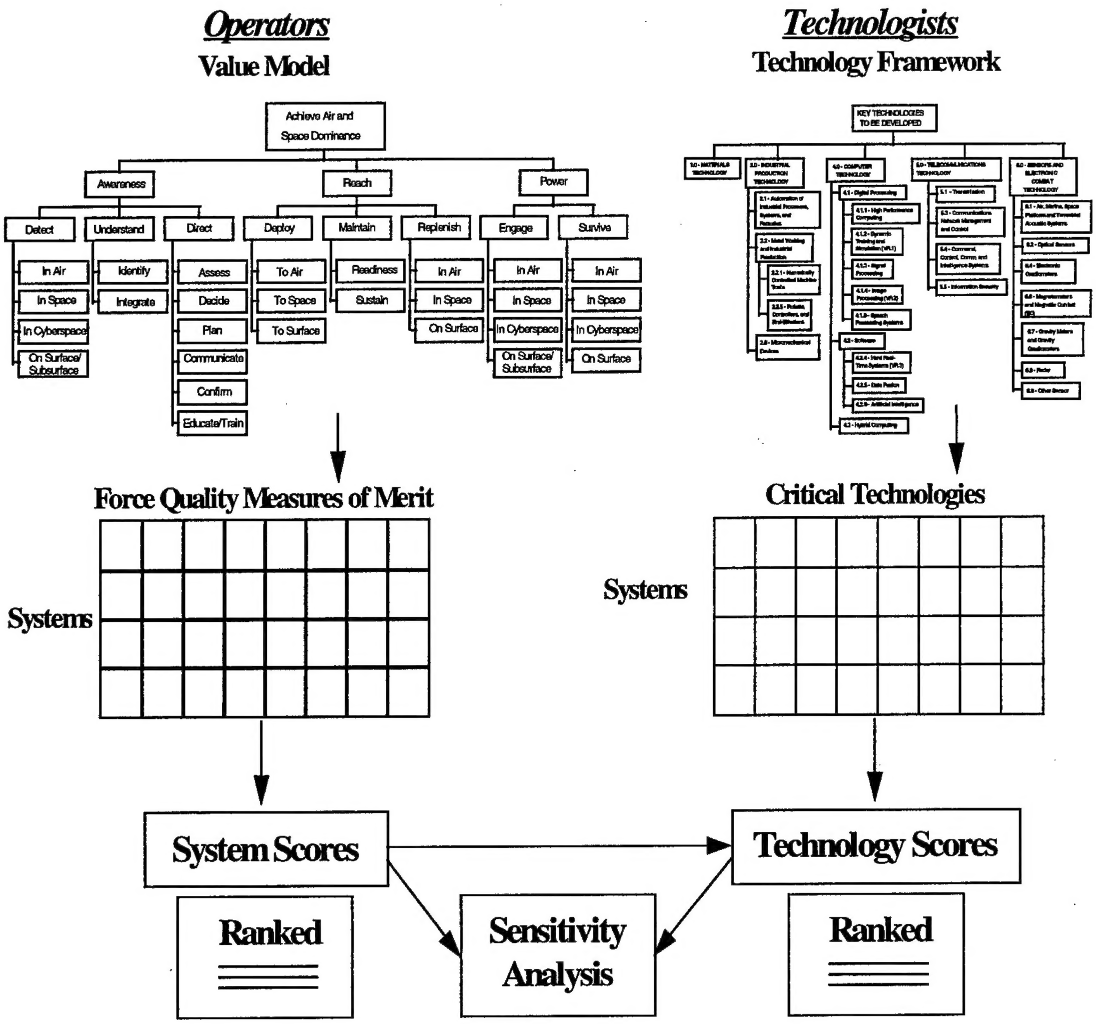

Figure 3. Operational Analysis Methodology

control, manipulate, deny, exploit, or destroy targets, including forces, people, equipment, and information, and the ability to survive while affecting targets. *Power* comes from the ability to *engage* and *survive.*

The requirement for a set of functions in a value model to be mutually exclusive and collectively exhaustive results in two critical implications. First, these three foundations *2025* functions should encompass every future air and space force operational activity. Second, *awareness, reach,* and *power* are the only operational activities that contribute to the overarching objective of air and space dominance.

Figure 5 demonstrates a complete path from the overall objective to the bottom of a branch of the value hierarchy ending with a scoring function for the measure of merit associated with communications capacity. Following the outlined boxes through the hierarchy, we recognize that under the awareness function, there are three tasks, *detect, understand,* and *direct*. The *direct* task is composed of six subtasks, of which *communicate* is a member. The *communicate* subtask has five force qualities capacity. A *force quality* defines a desired attribute of a system to achieve a subtask. Keeney (1992) states that, "[force qualities] should be measurable, operational, and understandable."

Each force quality has a *measure of merit* that is used to gauge system performance. In the 2025 era, our technology experts predicted that

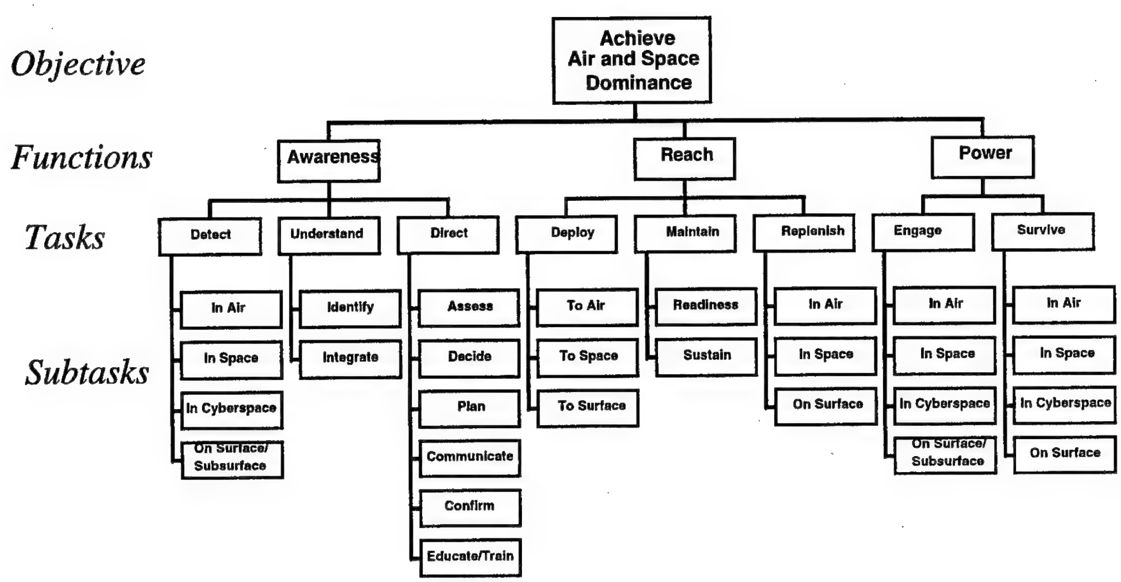

Figure 4. *Foundations 2025* Value Model

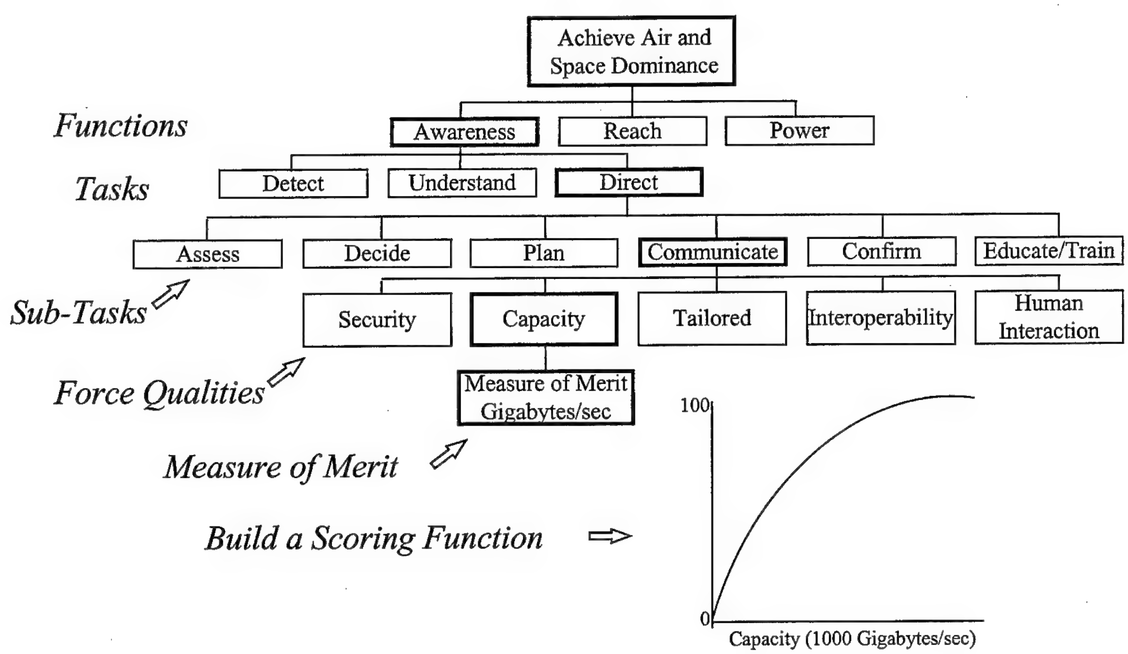

Figure 5. Value Framework Branch Example

the measure of merit for the *capacity* force quality would be how many "1000 Gigabytes per second" could be handled by a communications channel.

VFT *scoring functions* provide a quantitative means for measuring the relative system performance for each measure of merit. For Figure 5 the corresponding scoring function converts a communications capacity into a score from 0 to 100. The example scoring function was created based on operational insights which demonstrate that a curve with decreasing marginal returns accurately depicts the operational utility of this measure of merit.

The value model was developed following the techniques recommended by Keeney (1992). Tasks and subtasks for each function are listed in Figure 4, force qualities were identified for each subtask, and corresponding measures of merit were continually refined during a succession of meetings. After working with each ***AF 2025*** white paper team, the OA team was able to reduce the list of force qualities from the initial number of about 1,200 to the final number of 134. The *2025* Operational Analysis Technical Report (Jackson, et al, 1996b) contains complete descriptions of all tasks, subtasks, force qualities, measures of merit, and scoring functions.

After the hierarchical structure of the value model is complete, the decision maker must determine the relative importance of the tiers within the hierarchy. This is accomplished by the decision maker assigning numerical weights across each tier of the value model; for a linear additive value model these weights must sum to one.

With the development of ***Foundations 2025*** complete, the next step in the ***AF 2025*** operational analysis was to use the model to evaluate systems. The ***AF 2025*** white papers provided the key information for identification and definition of the systems.

System Concept Identification

Following a thorough review of the ***AF 2025*** white papers, the OA team identified 43 unique high-leverage systems which fall into the broad categories in Figure 6. Also included is a brief description of each system. For an analysis, a system was defined to be "a functionally related group of elements that performs a mission or task." Although some of the identified system concepts were extracted from a single white paper, many systems, particularly those involving the collection and management of information, were composites drawn from capabilities detailed in several of the papers. Complete system descriptions are contained in the ***2025*** Operational Analysis Technical Report (Jackson, et al, 1996b).

Alternate Futures

The ***AF 2025*** Alternate Futures team generated and then analyzed over 100 candidate drivers deemed to be forces acting on the future (Engelbrecht et al, 1997). They selected the three most important drivers to define a strategic planning space in which alternate futures could be developed (Figure 7). Definitions for each of these three drivers are following.

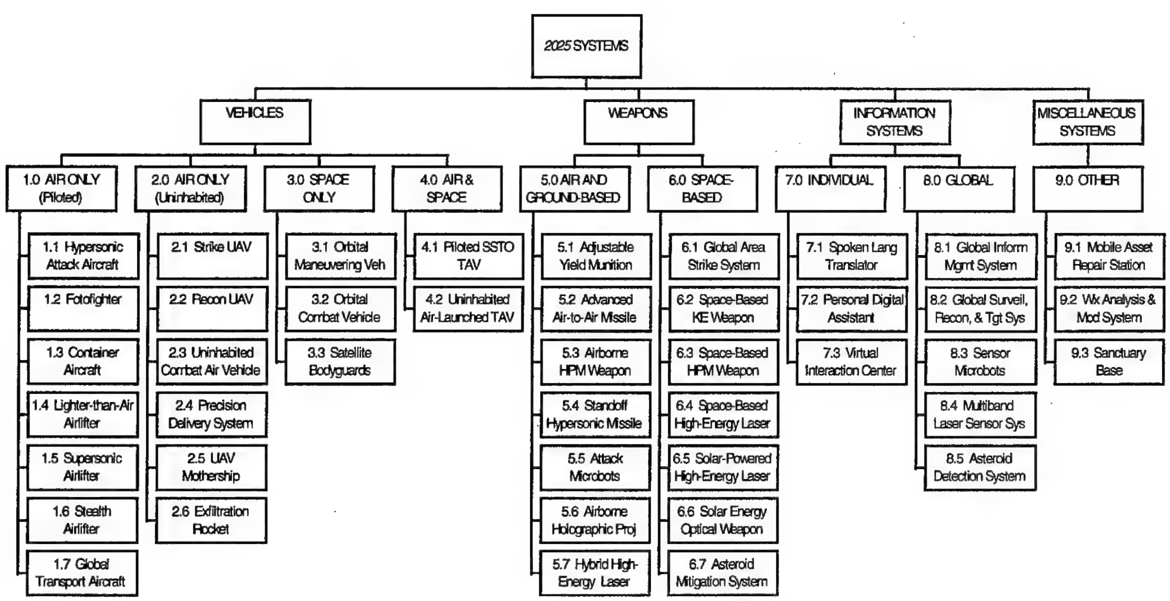

Figure 6. System Hierarchy

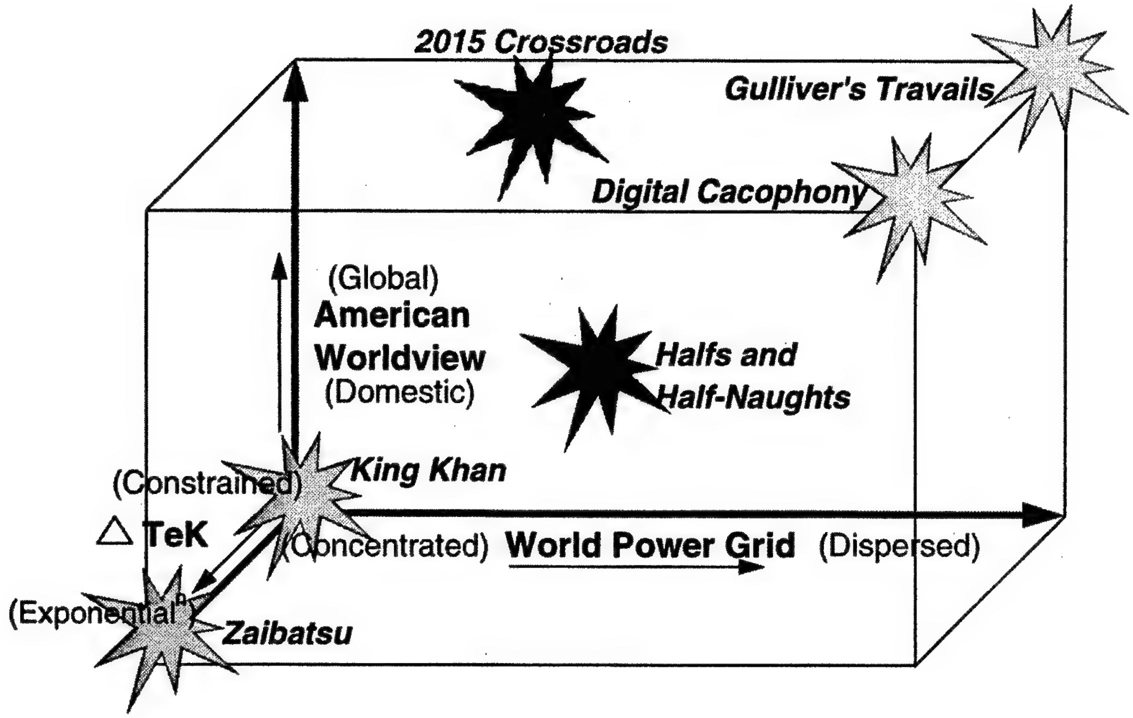

Figure 7. *AF 2025* Alternate Futures Strategic Planning Space

American Worldview—This driver is the US perspective of the world which determines the nation's willingness and capability to interact with the rest of the world. American Worldview captures the dominant US focus regarding international affairs. The US can be primarily internally focused, perhaps even isolationist, or the US can be actively engaged in activities around the world. The poles of American Worldview are domestic and global.

Δ TeK—This driver is the differential in the growth rate, proliferation, leverage, and vitality of scientific knowledge and technical applications and their consequences. Δ TeK describes the rate of change in both the proliferation and advancement of technology. The two poles of Δ TeK are constrained and exponential. Constrained Δ TeK implies that technology is advancing at an evolutionary rate and that its availability is limited to a relatively small number of actors. Exponential Δ TeK occurs when there are revolutionary breakthroughs in technology that are rapidly proliferated throughout the world.

World Power Grid—This driver describes the generation, transmission, distribution, and control of power throughout the world. This power is a combination of economic, political, and information sources of power as well as military strength. The two poles of this driver are Concentrated and Dispersed. A concentrated world power grid exists when few actors have the means or will to influence others. When a myriad of groups or individuals can change the future, the world power grid is dispersed.

Six alternate futures were chosen from this planning space to provide a diverse set of future conditions used to evaluate the proposed air and space systems. Four futures are extremes and were selected to bound the strategic planning space: *Gulliver's Travails*, *Zaibatsu*, *Digital Cacophony*, and *King Khan*. The world of *Halfs and Half-Naughts* was chosen for its centrality. Finally, the *2015 Crossroads* future provides a conservative bridge between today and 2025.

In *Gulliver's Travails*, the US is overwhelmed with worldwide commitments, counterterrorism and counterproliferation efforts, humanitarian operations, and peacekeeping operations. In *Zaibatsu*, multinational corporations dominate international affairs, loosely co-

operating to create a relatively benign world. *Digital Cacophony* is the most technologically advanced world resulting in great power and independence for the individual, but also creating a world of social isolation, fear, and anxiety. *King Khan* is a world where US dominance has waned due to domestic problems, an economic depression, and overshadowing by a rising Asian colossus. The world of *Halfs and Half-Naughts* is dominated by conflict between the "haves" and "have-nots" and by dynamically changing social structures and security conditions. *2015 Crossroads* uses programmed forces from 1996–2001 to fight a major conflict; it presents the US with a strategic challenge in 2015 that could lead to any of other alternate futures by 2025.

The six alternate futures were used to stimulate the creativity of the participants and to assess six sets of weights for the value model. We then were able to do sensitivity analysis to find out how the system preferences changed with alternate futures.

Weighting the *Foundations 2025* Value Model Across Alternate Futures

The first step in using the ***Foundations 2025*** value model is for the decision maker to determine the relative importance of the functions, tasks, subtasks, and force qualities. Because different futures dictate a different set of required air and space capabilities, the OA team obtained value model weights from the ***AF 2025*** participants for the six alternate futures. As each alternative future was briefed to the ***AF 2025*** participants, the Operator teams were required to submit consensus weights which represented their team's view of the portions of the value hierarchy which would have the most operational value in the future scenario. The weights for each future are contained in the ***2025*** Operational Analysis Technical Report (Jackson, et al, 1996b).

Each system was scored against every measure of merit for each force quality. The system scores for each measure of merit were weighted at each level of the hierarchy by the value weights. As this process is continued—working upwards to the top of the value framework—a weighted average of the system's scores across the entire value framework was developed. This overall weighted average was the overall system value.

Based on the weights for any alternate future, the overall value of a system concept can be calculated by multiplying the score a system concept received for each measure of merit by the corresponding weight for the measure. The overall value function has the following form,

$$Overall\ Score\ System_X = \sum_{n=1}^{N} w_i w_j w_k w_l w_m Score_{Xn}$$

where the w's are the weights for each level in the hierarchy; i for function, j for task, k for sub-task, l for force quality, m for measure of merit, and Score is the value System X received on the *n*th measure of merit.

Use of the linear additive value function presupposes additive independence for each of the measures of merit (Kirkwood, 1997). We did not test the 134 measures for additive independence because time would not permit the conduct of this onerous task. We did test and find the top level of the hierarchy to be mutual preferential independent. Based on this finding, consistent effort to maintain mutually exclusive development within the hierarchy, and recommendations within the literature to assume the additive model for rough, first cut analysis, we elected to use the additive model.

RESULTS

This section describes how ***Foundations 2025*** was used to evaluate future air and space systems and the analysis results.

Scoring the System Concepts

A scoring team, selected from the OA team, scored all 43 systems against each measure of merit in ***Foundations 2025***. A consensus-seeking approach was used to obtain each score. The team was not permitted to know the shape of the scoring function.

The final results of the system scoring are displayed in Figure 8. The vertical axis is the value from the system evaluation on a scale of 0 to 100, where a system value of 0 equates to no value on any of the 134 scoring functions.

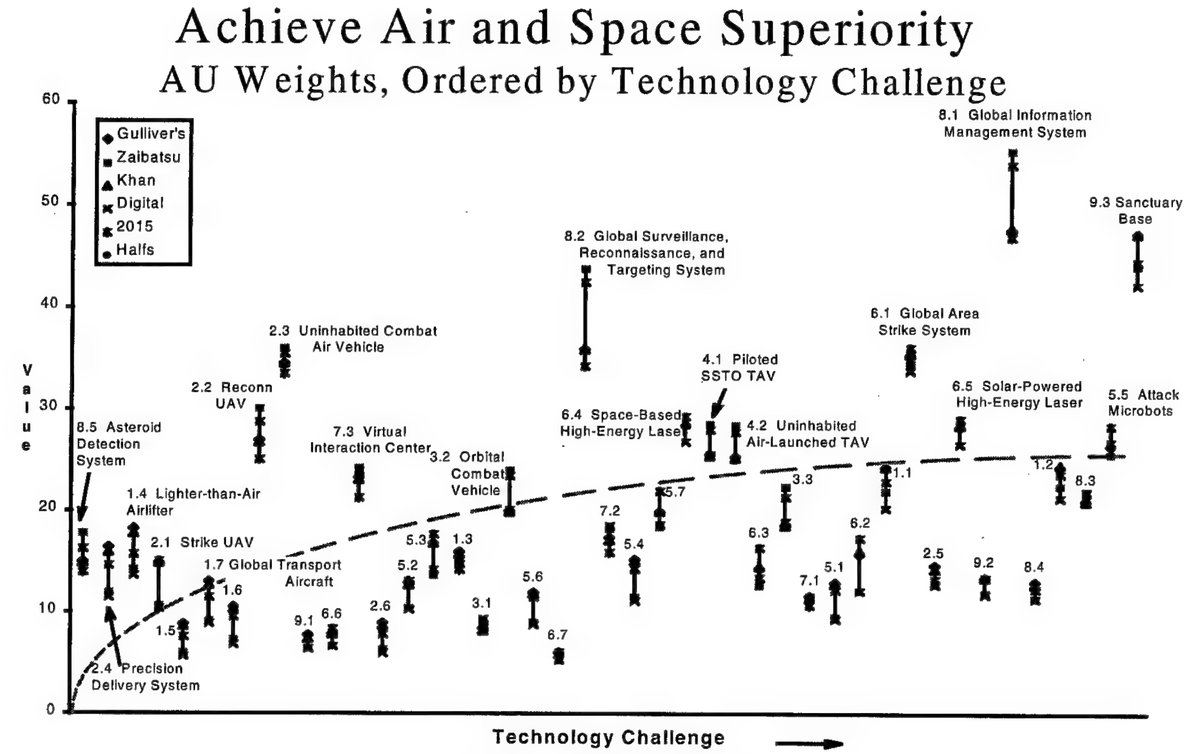

Figure 8. Final System Values

The horizontal axis is a rank ordering of the systems according to the OA team's assessment of the relative amount of technical challenge to develop each system. Figure 8 shows system values for all six of the alternate futures. Each system's values for the various futures are plotted and connected with a line to show the variation of that system's value across the alternate futures, and hence the entire strategic planning space.

The curved dashed line provides a further reference for comparing systems. In the OA team's estimation, systems above the line may have sufficient value to offset the technical challenge of producing such a system. Thus, systems to the left of the chart need less value to be attractive options than systems to the right of the chart, because the difficulty of achieving the capability is much less. The location of the line is notional. It was drawn fairly low so as not to prematurely eliminate any potentially promising systems from consideration.

The highest-value systems evaluated in this study are the Global Information Management System (GIMS), Sanctuary Base, Global Area Strike System (GLASS), Global Surveillance And Reconnaissance System (GSRT), and uninhabited combat air vehicle (UCAV). GIMS has the highest value but high technical challenge; GSRT performs some of the functions of GIMS, but with less technical challenge. Because of this, GSRT could be considered a "stepping stone" to GIMS. Both GLASS and UCAV score well because of a strong Awareness component to complement their Power contributions, and UCAV is the most feasible of all the high-value systems in the near term. The Sanctuary Base has high value but also the highest technical challenge, and may remain infeasible even beyond 2025. The ***2025*** Operational Analysis Technical Report (Jackson, et al, 1996b) contains tables of each system's value for each future and weight set.

The scoring results highlight the fact that a complex system (a system of systems) outperforms any of its components. This is because of the additive nature of the scoring functions. The complex system scores more broadly since it contains the capabilities of all of its components. Conversely, since component systems may have complementary capabilities, the com-

plex system will generally score less than the simple sum of the component system scores.

Finally, Figures 9–11 contain graphs similar to that of Figure 8, but for the Awareness function, the Deploy task of Reach, and the Power function, respectively. These figures allow the reader to note the systems that score well for a particular function. For example, Figure 9 highlights the best systems in terms of the Awareness function. Such a level of detail may prove useful when conducting mission area analysis to determine required improvements for specific functional areas. In fact, the software used in this analysis can display the system values at any level of the value model (Logical Decisions™, 1995).

Scoring the Technologies

Once the 43 systems contained in the white papers were identified, the OA team qualitatively analyzed each system to identify which technology areas would be key to achieving the stated system capabilities. Only those technology areas needing development were considered. For example, if a specific technology area was critical to a given system's capability but no new advances were needed in this area for the system to achieve its full capability, then this technology area was not identified as "high leverage" for this particular system.

The OA team felt it highly desirable to identify and group technologies according to a key baseline document. *The Militarily Critical Technologies List* (1992) was used as the basis for identifying key technologies in each system (Figures 12a and 12b). Across the 43 evaluated systems, 43 key technology areas were identified (this number is a coincidence).

To eventually rank technologies by their impact on future air and space capabilities, the team assigned a relative weight to each technology embedded in a particular system. The weights selected add up to 100 for each system, and so can be thought of as percentages of the system's dependence on each technology needing development. For example, the five piloted single-stage-to-orbit (SSTO) transatmospheric vehicle (TAV) technologies were weighted as follows:

Technology Area	Weight
High-energy Propellants	25
Aerospace Structures and Systems	25
Ramjet, Scramjet, Combined Cycle Engines	20
Advanced Materials	20
High-performance Computing	10

Once the system-versus-technology matrix was developed, the procedure for scoring the technologies was straightforward. For each technology, its contribution to each system was multiplied by the system value, and the result-

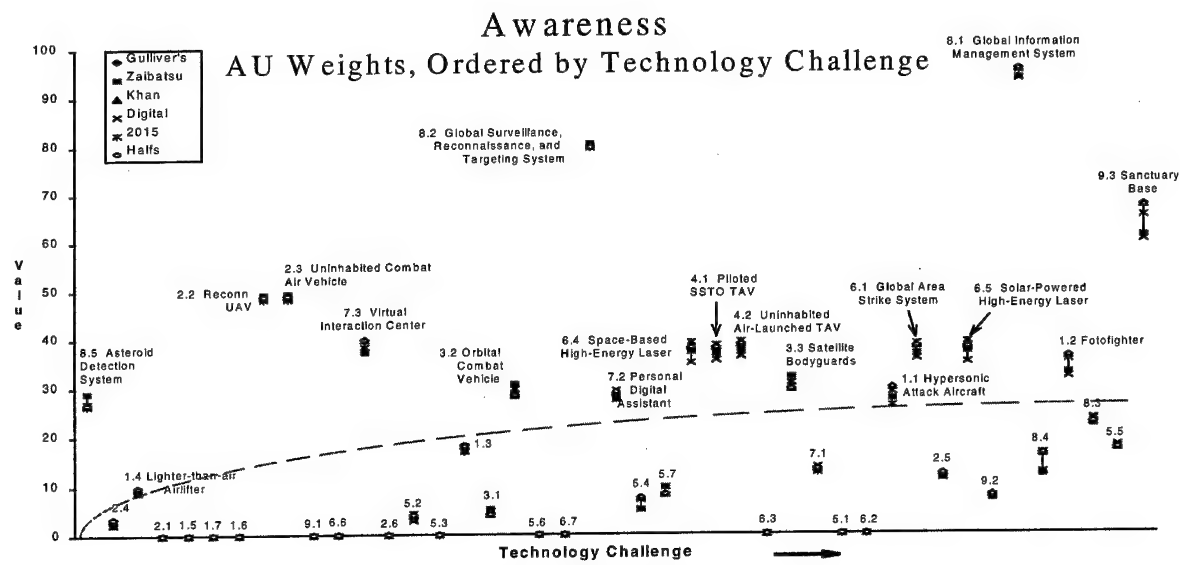

Figure 9. *Awareness* Values

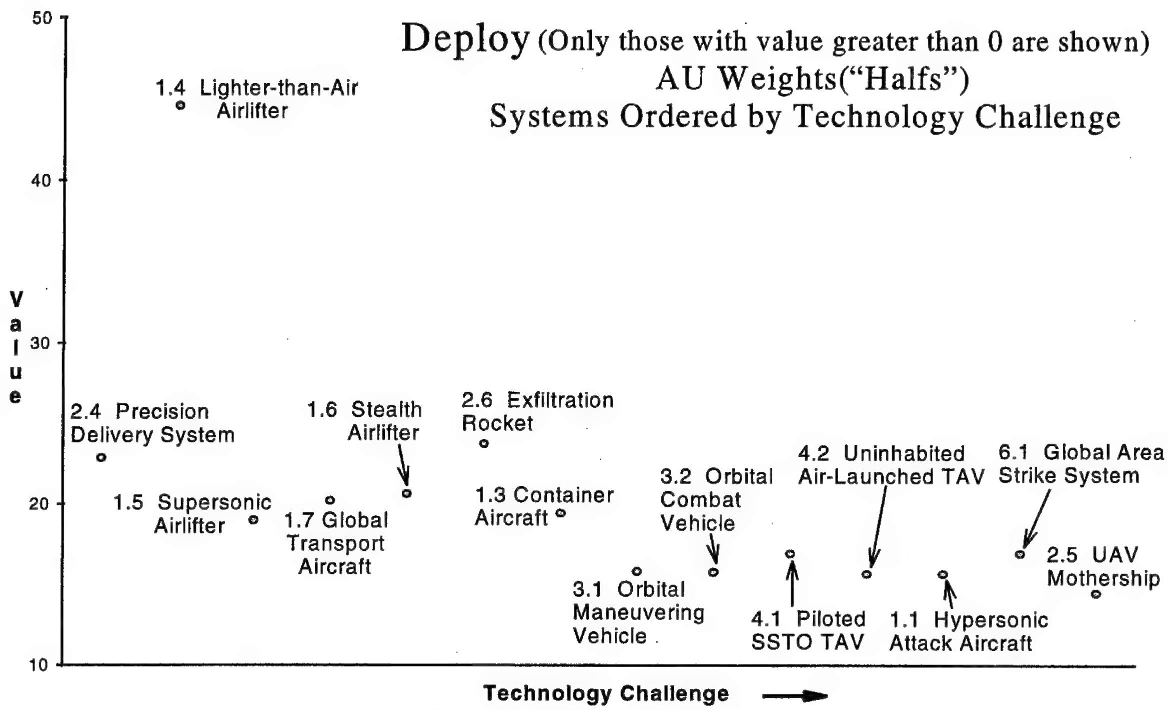

Figure 10. Deploy Values - "Halfs" Future

ing products were summed across all systems. The result was a set of technology scores (normalized to a maximum score of 100) that takes into account both the technologies' degree of contribution to future air and space systems and the importance of those systems to air and space operations. This scoring was then repeated for each alternate future since the system value changed as the weights changed across alternate futures. For all six alternate futures, the technology areas clearly divided into three groupings: the top seven technologies (high leverage), the next five technologies (moderate leverage), and the bottom 31 technologies (less leverage). Figure 13 shows an expanded view of the top two technology groupings.

A common trend among the higher-leverage technologies was that they had wide applicability over the systems. The high-leverage technologies scored in at least 13 different systems; the maximum number of systems where any technology area scored was 27. Moderate-leverage technologies scored in 8 to 12 different systems. High-performance computing was the technology area with the broadest coverage over the systems considered.

After each technology area had been scored, the technical assessment group assembled determined the key technology development leader, the DoD or the commercial sector, for that particular area. They further ascertained the direction of each developmental effort, whether from the DoD to the commercial sector, from the commercial sector to the DoD, or remaining constant. Table 1 summarizes the key technology development leaders for the high leverage technologies: The ***2025*** Operational Analysis Technical Report provides this data for all technologies (Jackson, et al, 1996b).

CONCLUSIONS

The ***AF 2025*** study was publicly released by General Fogleman and Air Force Secretary Widnall in September 1996 (Air Force ***2025*** Final Report Homepage, 1996). General Fogleman stated,

"Air Force 2025 demonstrates to the American people that the nation's Air Force is thinking creatively and seriously about the future. We brought in a variety of outside advisors, including some of

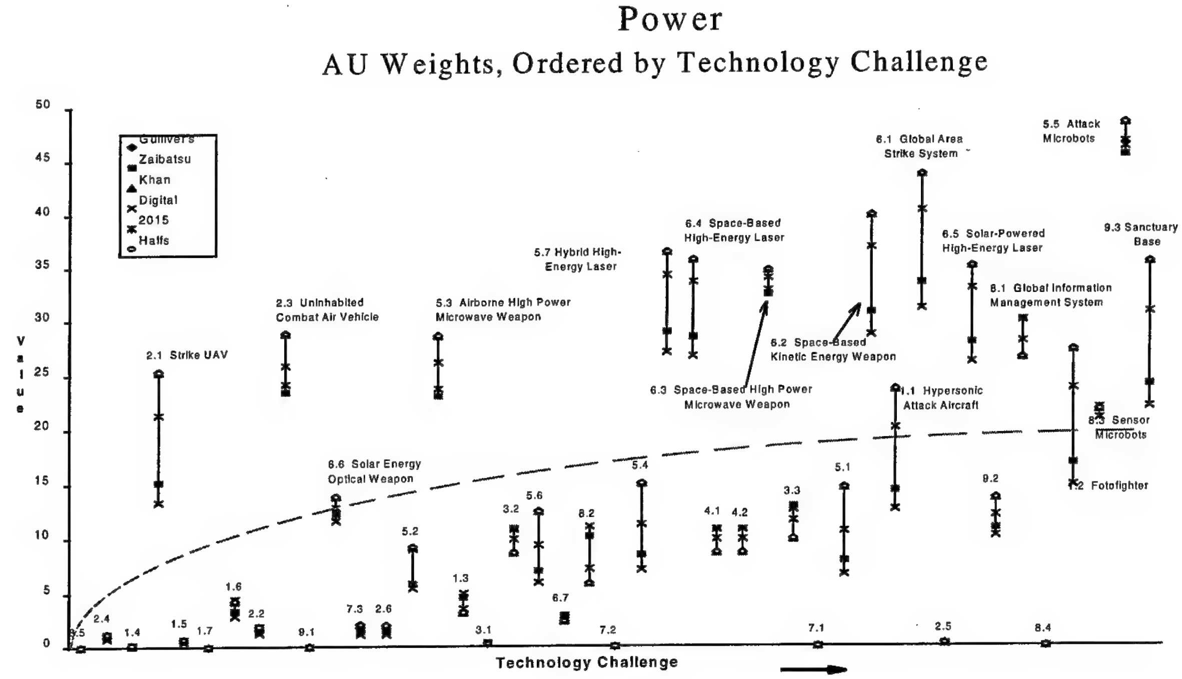

Figure 11. Power Values

the world's most highly regarded futurists, experts on a wide variety of topics, and forward looking thinkers, including Alvin Toffler, Admiral William Owens, and many others to build a picture of the future. As part of the comprehensive long-range planning effort, the alternate futures discussed in Air Force 2025 will help develop a strategic vision and prepare the United States Air Force for the challenges of the 21st century"

—Gen Ronald R. Fogleman, Air Force *2025* Final Report Homepage, 1996

The study has been reported on by the defense press (Cooper, 1996; Heronema, 1996; Fulghum, 1996; Tirpak, 1996). The study reports covering all aspects of the ***AF 2025*** study can be obtained on the Internet (Air Force ***2025*** Final Report Homepage, 1996).

The ***AF 2025*** Operational Analysis was a key milestone in the ***AF 2025*** process and provided a number of unique contributions. Most importantly, it met its fundamental purpose—the OA identified future air and space systems required to support air and space dominance and the key technologies that will make those systems possible by capturing the overall values held by the ***AF 2025*** participants. ***Foundations 2025*** is distinguished by the large number of system concepts that were analyzed, the 30-year focus into the future, and the fact it was developed through a bottom-up approach. ***Foundations 2025*** offers a potential new framework for future air and space doctrine that can be easily modified (separated into three models: *awareness, reach,* and *power*) by Air Force major commands for use in their mission area analysis process. Thus, the model presented is an aid to current and future senior decision makers concerned with the employment of air and space power.

System Implications

The ***AF 2025*** study produced a number of excellent system concepts for employing air and space power in the future. This analysis strongly suggests that the high ground of improved *awareness* offers significant potential for achieving future air and space dominance. Typically, top-scoring systems possessed higher degrees of *awareness* and/or were predominantly *space* systems:

- Global Information Management System (GIMS)

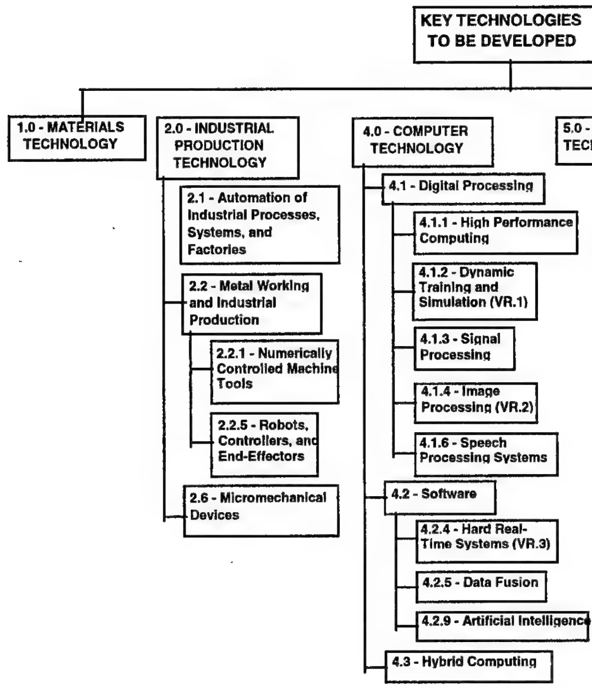

Figure 12a. Technology Framework

- Sanctuary Base (SB)
- Global Surveillance, Reconnaissance, and Targeting System (GSRT)
- Global Area Strike System (GLASS)
- Uninhabited Combat Air Vehicle (UCAV)
- Space-Based High-Energy Laser (Space HEL)
- Solar High-Energy Laser (Solar HEL)
- Reconnaissance Unmanned Air Vehicle (Recon UAV)
- Attack Microbots
- Piloted Single-Stage-to-Orbit (SSTO) Transatmospheric Vehicle (TAV)
- Uninhabited Air-Launched TAV

Seven of the top eight systems emphasized the *awareness* function. GSRT can be thought of as a first generation GIMS; it obtains most of the value of GIMS with much less technological challenge. Both systems scored high because the management of information tasks was assigned high weights by the ***AF 2025*** participants. Such systems go beyond data fusion to knowledge fusion; they provide a global view that could revolutionize military operations. Improved awareness is critically important because it enables virtually all other air and space force capabilities.

Control of the high ground of space will be very important. Of the top 11 systems, only three do not operate in space or use major space-based components. Space-based weapons are significant contributors to the operational effectiveness of future air and space operations by providing key capabilities in space defense, ballistic missile defense, defense of terrestrial forces, and terrestrial power projection. Of the weapon systems evaluated, the Space High Energy Laser (HEL) seems to hold the most promise, largely because its optical system could also be used for surveillance and imaging missions (an *awareness* function). Other systems that scored well were the Solar HEL, the Space-Based Kinetic Energy Weapon, and the Space-Based High-Powered Microwave. *Spacelift* is another essential contributor to future space operations. Reusable transatmospheric vehicles provide critical lift capability to improve virtually all space force capabilities.

Improved *power* will be best accomplished through improved speed, precision, and on-station time. The ***AF 2025*** white paper teams viewed the reduction of the OODA (observe, orient, decide, act) loop to an OODA "point" as critical to future operations. All of the "shooter" systems that emphasized *awareness* scored high by reducing the time to identify, target, and kill threats. Among these systems are the GLASS, the Space HEL, and the Solar HEL. The envi-

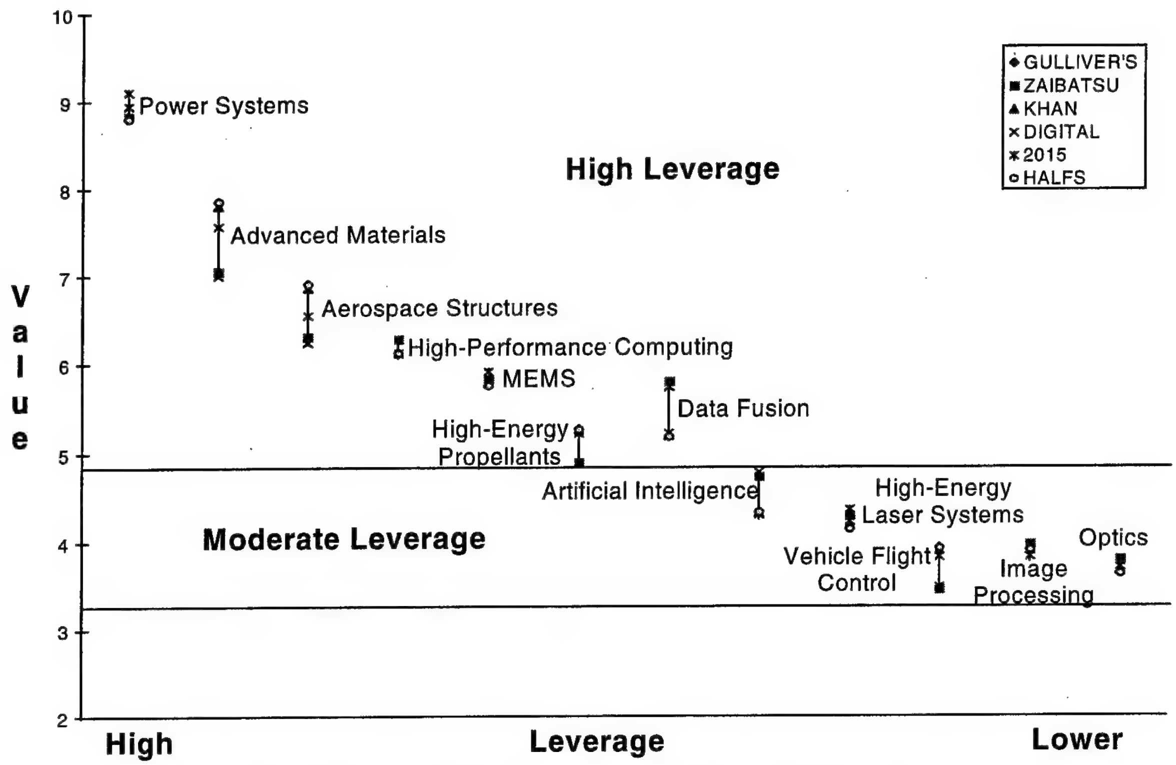

Figure 13. Top Twelve Technology Rankings (All 43 Systems)

Table 1. Technology Development Leaders for High Leverage Technologies

KEY TECHNOLOGY	DoD LEAD	BOTH DoD & COMM	COMM LEAD
4.2.5 Data Fusion	X→		
10.3 Power Systems	X		
2.6 Micromechanical Devices		X→	
9.5 Aerospace Structures		X→	
1.0 Advanced Materials		X	
12.7 High-energy Propellants	X		
4.1.1 High-performance Computing			X

sioned systems emphasized the increased need for precision over mass, especially with respect to avoiding excess collateral damage.

The near-real time response requirement of future combat meant many of the systems either were global and/or pilotless, such as uninhabited air vehicles (UAVs). It is important to note that while the UAVs are uninhabited, none are envisioned as operating autonomously without a human in the loop. Such an improved on-station *power* capability is important because it provides a constant deterrent to enemy forces.

Technology Implications

The technology assessment portion of the study identified seven high-leverage technologies that are important to a large number of high-scoring systems:

- Power Systems
- Advanced Materials
- Aerospace Structures
- High-Performance Computing
- Micromechanical Devices

- High-Energy Propellants
- Data Fusion

Advances in these areas show promise to substantially improve a wide range of air and space operations. Other technologies were also important, but contributed to only three or four of the high-value systems. Among the top-scoring medium-leverage technologies were:

- Artificial Intelligence
- High-Energy Laser Systems
- Vehicle Flight Controls
- Image Processing
- Optics

Some of the high-leverage technologies enabling ***AF 2025*** systems, such as high-performance computing, are being pursued aggressively in the commercial sector. Others, such as power systems, have lower commercial interest. An expanded analysis of the ***AF 2025*** systems and their embedded technologies can help develop the most effective DoD investment strategy.

It is important to remember that the analysis did not take into account the cost or risk of developing any of the system concepts. We looked only briefly at the technological challenge of each system concept. While this study indicates some systems and technologies that show promise for dramatically improving the effectiveness of air and space operations, there are other important factors that need to be considered before making an investment decision.

Operational Analysis Lessons Learned

Foremost among the ***AF 2025*** OA lessons learned was that the VFT approach worked very well. The ***Foundations 2025*** value model has been used to evaluate systems that span the full range of future air and space combat operations. These systems are conceptual system ideas that will require significant research and development to design and evaluate. The OA provided a structure to incorporate the subjective judgments of operational and technical experts to produce objective, traceable, and robust results.

The focus of the value model, ***Foundations 2025***, was on the employment of air and space forces. This model does not consider the USAF functional areas required to organize, train, and equip. By avoiding the current names of mission (nouns), we developed a visionary value model (using verbs).

Major Implications for the Future

A number of senior decision makers have viewed the model and commented that the best use of ***Foundations 2025*** may be an analysis of systems within the distinct spheres of *awareness*, *reach*, and *power*. They envision separating and developing each function of the model further (refining the tasks, subtasks, force qualities, measures of merit, and scoring functions) and studying which *awareness* (or *reach* or *power*) systems are most promising. These three separate models could be effective mission area analysis tools for the major commands.

The completed ***Foundations 2025*** value model is the starting point for *Value-Focused Thinking* with the Department of Defense. For any function, task, or subtask, the model can be used to evaluate current and projected systems. Next, the acquisition community can focus on how new concepts can be developed to significantly increase value. Various creativity techniques can be used to develop these new concepts.

Another opportunity to capitalize on the ***Foundations 2025*** model is to use it as a framework for future air and space doctrine. Because it identifies fundamental functions, tasks, and subtasks, it could be the foundation for joint doctrine for future air and space warriors. The ***AF 2025*** analysis techniques could be used to develop an entirely new joint military doctrine free from current institutional bias.

Summary

Foundations 2025 represents five important analytic advances. First, the collection of scoring functions serves as an invaluable resource, even outside the ***AF 2025*** study. Second, the use of verbs to specify tasks was a useful step in the value model evolution. Third, building from the bottom up allowed ***Foundations 2025*** to be free from institutional bias and capture the visionary thinking of ***AF 2025***. Fourth, ***Foundations 2025*** is a very robust value model. With five tiers consisting of an overarching *objective*, three *functions*, eight *tasks*, 29 *subtasks*, and 134 *force qualities* (each with a corresponding *measure of merit* and *scoring function*)—and all

weighted across six alternate futures—the model can be used to evaluate very diverse systems. Finally, ***Foundations 2025*** is cast further into the future than any other known military value model.

ACKNOWLEDGMENTS

The ***AF 2025*** study benefited from the involvement of many senior-level leaders and the over 200 study participants. In addition, Study Chair, Lt Gen Jay Kelley, USAF, the Study Director, Col Richard Szafranski, USAF, and the Research Director, Col Joseph "Jae" Engelbrecht Jr., USAF, provided important direction and advice.

ENDNOTES

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REFERENCES

Air Force Doctrine Document-1: Air Force Basic Doctrine, 15 August 1995, First Draft (Washington, DC: US Air Force, 1995).

Air Force ***2025*** Final Report Homepage, http://www.au.af.mil/au/2025/#2025 Final Report, November 8, 1996.

Burk, R. and Parnell, G. S., "Evaluating Future Space Systems and Technologies," *Interfaces*, Accepted July 1996.

Clemen, R. T., *Making Hard Decisions: An Introduction to Decision Analysis*. Boston: PWS-Kent, 1991.

Cooper, Pat, "U.S. Stealth Enhancements Are Key to Air Occupation," *Defense News*, September 16–22, 1996, pp. 1 and 66.

Cornerstones of Information Warfare (Washington, DC: US Air Force, 1995).

Engelbrecht, J. A., R. L. Bivins, P. M. Condray, M. D. Fecteau, J. P. Geiss II, and K. C. Smith. "Alternate Futures for 2025: Security Planning to Avoid Surprise," Air University Press, Maxwell AFB, AL, April, 1996.

Fogleman, R. L., Video teleconference between General Fogleman and ***AF 2025*** participants, September 6, 1995.

Fogleman, R. L., Message from General Fogleman to Air University, 23 December 1994.

Fulghum, David, "Strikestar 2025 to Combine F-117 Stealth, UAV Range," *Aviation Week & Space Technology*, September 30, 1996, pp. 74–75.

Heronema, Jennifer, "USAF Looks Spaceward in Strategy For Future," *Defense News*, September 16–22, 1996, pp. 4 and 66.

Jackson, J. A., Jones, B. L., Lehmkuhl, L. J., Conley, H., and Andrew, J. M., *An Operational Analysis for 2025: An Application of Value-Focused Thinking to Future Air and Space Capabilities*, Air University Press, Maxwell AFB, AL. October 1996a.

Jackson, J. A., Jones, B. L., Lehmkuhl, L. J., *2025 Operational Analysis Technical Report*, Air University Press, Maxwell AFB, AL. October 1996b.

Joint Vision 2010, America's Military: Shaping the Future (Washington, DC: Joint Chiefs of Staff, Draft, January 1996).

Keeney, R. L. *Value-Focused Thinking: A Path to Creative Decisionmaking*. Cambridge, Massachusetts: Harvard University Press, 1992.

Kent, G. A., and Simons, W. E., *A Framework for Enhancing Operational Capabilities*, R-4034-AF (Santa Monica, CA: RAND Corporation, 1991).

Kirkwood, C. W., *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets*, Belmont, California: Duxbury Press, 1997.

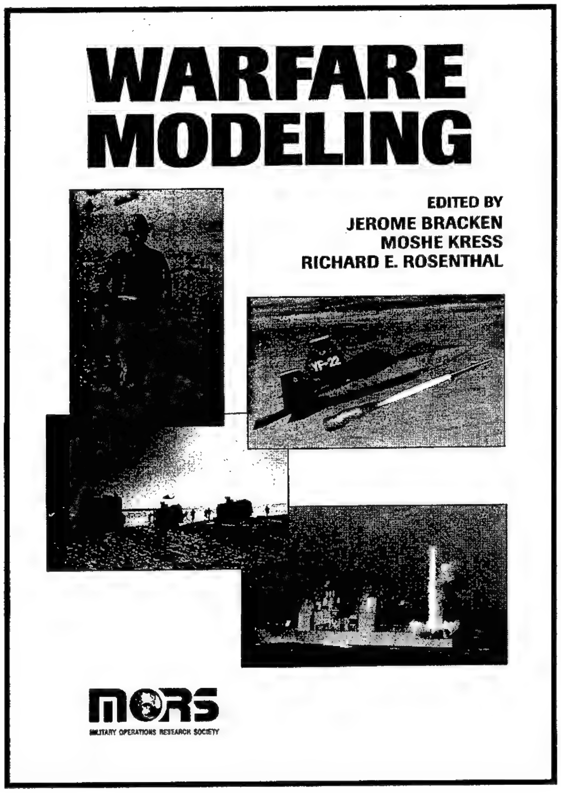
Logical Decisions™, *Logical Decisions for Windows*, Golden, CO 1995.

The Militarily Critical Technologies List. Washington, D.C.: Office of the Undersecretary of Defense for Acquisition, October 1992.

National Military Strategy of the United States of America, 1995 (Washington, DC: US Government Printing Office).

Parnell, G. S., Jackson, J. A., Conley, H. W., Lehmkuhl, L. J., and Andrew, J. M., "Building a Value Model: Foundations 2025: A Framework for Future Air and Space Forces", *Management Science*, forthcoming 1998.

Tirpak, John A. "Air Force 2025," Air Force Magazine, December, 1996.



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Appraising Warfighting Concepts with Wargaming Simulations

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OR METHODOLOGY: Wargaming
APPLICATION AREA: Modeling, Simulation, and Gaming

ABSTRACT

In 1996, the Joint Warfighting Center (JWFC) completed a wargaming effort for the Defense Science Board (DSB). JWFC's six-week effort used a high-resolution war game simulation, the Joint Conflict Model, to support the DSB's 1996 Summer Study, *Tactics and Technology for 21st Century Military Superiority*.[1] The DSB summer study explored warfighting concepts to enable "relatively small (the size to be determined) and rapidly deployable forces (or teams)—specially equipped, trained and supported by remote sensors and weapons—to accomplish missions heretofore only possible with much larger and massed forces."[2]

The purpose of this paper is to describe how a wargaming simulation normally used for training military leaders was used to investigate a warfighting concept. It begins with a short description of the JWFC appraisal approach. Next the DSB issue and basic scenarios are presented. The majority of the paper then describes how the JWFC appraisal team focused and explored the DSB issue through specific scenario vignettes, definition of variables, and measurement of results.[3] Since the objective of this paper is to describe the JWFC appraisal methodology, only a sample portion of the JWFC study results will be presented and the conclusions presented at the end of this paper will discuss the wargaming approach, not the specific study results.[4] Because the JWFC effort was only one segment of the total DSB undertaking, the material presented here is neither a comprehensive review of the entire DSB summer study nor a critique of the warfighting concept.

THE JWFC APPROACH TO WARGAMING APPRAISALS

Expertise in using simulations to facilitate the training of joint command and staff decision processes shaped JWFC's appraisal effort.[5] The challenge in using a wargaming simulation for the DSB study was creating a hybrid methodology combining appropriate elements of training event and analytical experiment design. Currently, many military training and analysis activities use simulations to create experiments ("events" in joint training lexicon) but usually differ in their treatment of human decision processes. In most simulation-based analytical experiments, human decision processes are minimized or incorporated into the simulation's algorithms. In contrast, simulations used for commander and staff training events must respond to human decision processes. The JWFC appraisal process borrowed techniques from both treatments and created a simulation-based experiment with defined measurements and variables that responded to human decision processes. The variables, however, were not changed incrementally as is done in most analytical experiments. Instead they were changed qualitatively or by an order of magnitude to observe their effects. In addition, the results of the JWFC wargaming experiment synthesized numerical data and expert observations of the war gamers.[6] (Throughout the remainder of this article, "wargaming" will be used to describe an event or experiment that centers around mission-related military decision processes. "Simulation" or "model" will be used to describe an inter-active computer-based representation of reality.[7])

Conducting a wargaming-based concept appraisal effort is an intensive process. Although JWFC's DSB effort was rapidly accomplished in six weeks, concept appraisal should normally be pursued at a more deliberate pace. The nature of the concept, complexity of the appraisal issues, and the customer's desired delivery date would determine the total time allocated to the process. Between four and six months is a reasonable estimate for a moderately complex concept appraisal project. Figure 1 depicts the process.[8]

Design Stage

- *Initial Design Conference*—Determine customer requirements and suitability of candidate issues to wargaming-based concept appraisal.
- *Concept Refinement*—Define candidate issues as concepts. Reduce concept to essential attributes or functions. Identify those attributes and functions that are suitable for wargaming. Review capabilities and limitations of available simulation models and other wargaming tools.
- *Initial Design of Experiment*—Using the concept's attributes and functions, describe essential elements of appraisal, determine variables (dependent and independent), formulate measures of merit

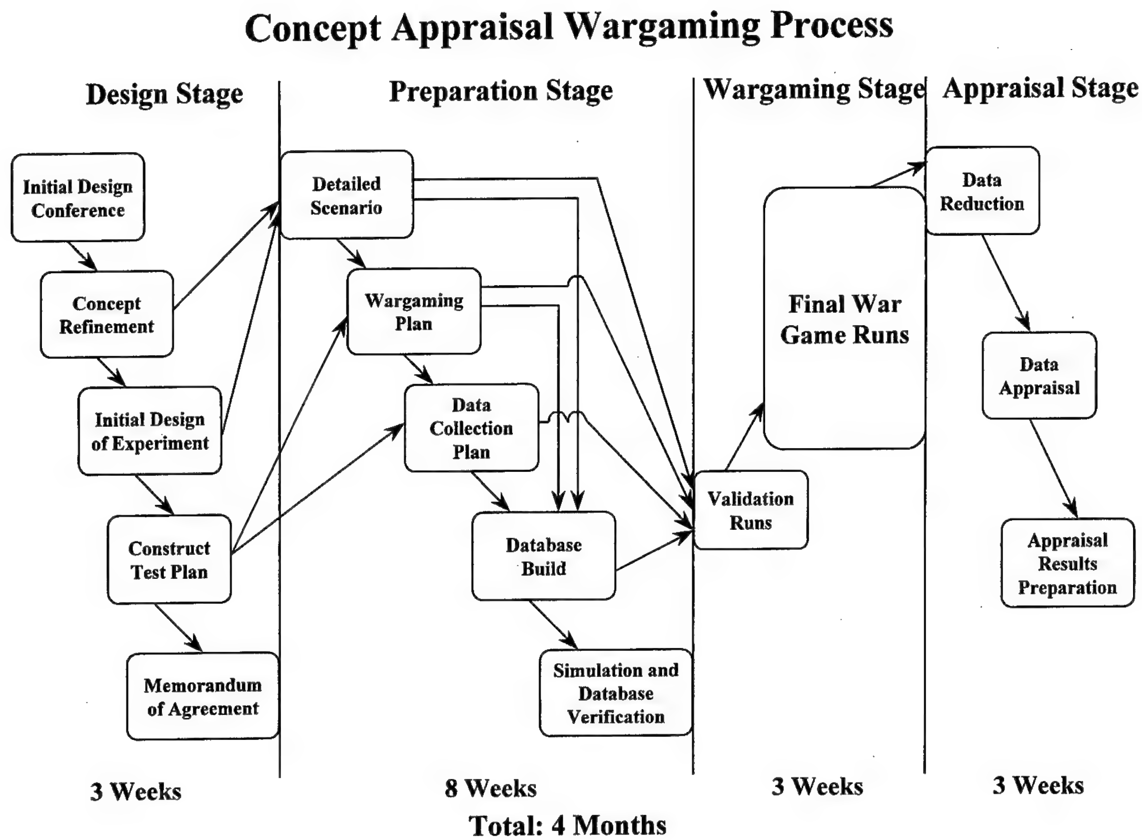


Figure 1. Schematic of the process used for the JWFC concept appraisal.

and enabling scenario elements. Select wargaming tool.

- *Construct Test Plan*—Based upon the design, develop the technical, wargaming and analytical support elements and schedule.
- *Develop Memoranda of Agreement*—Obtain customer agreement on the design and execution of the concept appraisal, including the content and format of the final concept appraisal product.

Preparation Stage

- *Produce Detailed Scenario*—Create the background, assumption and operational topography.
- *Develop Detailed Wargaming Plan*—Describe concept appraisal attributes and functions in terms of model events or processes.
- *Develop Detailed Data Collection Plan*—Determine data elements and source.
- *Build Database*—Create new or modify existing database.
- *Simulation and Database Verification*—Conduct functionality tests of the model and database based on how the warfighting concept is to be implemented in the simulation. Conduct model proficiency training for war gamers if required.[9]

Wargaming Stage

- *Validation Runs*—Run representative sample of wargaming events. Practice data collection process. Check results for reasonableness, consistency, and expected outcomes. Determine if modifications to test design or plan are needed.[10]
- *Conduct Final Runs*—Run all wargaming events and collect data. Evaluate each run for acceptability and data integrity. Repeat events that are unacceptable.

Appraisal Stage

- *Data Reduction*—Manipulate data into a format suitable for appraisal.
- *Data Appraisal*—Synthesize quantitative and observer-based data.
- *Prepare Concept Appraisal Results*—Produce and deliver final product to customer. The remainder of this paper will discuss a few of elements of this process.

CONCEPT REFINEMENT—THE DSB STUDY ISSUE AND SCENARIOS

The DSB Summer Study issue was: Can improved technologies enable small US land forces to perform missions previously accomplished by larger forces? The enabling concept was a combination of tactics and technology. Advanced sensors would be used to produce and distribute battlefield information that would provide local situation awareness to small land forces. These units would then rely on long-range indirect fires, such as arsenal ships or armed aerial vehicles, to engage adversaries while avoiding direct engagement. To be feasible, from both effectiveness and survivability perspectives, the timelines between the acquisition and engagement of targets must be very short.[11] The DSB Summer Study postulated seven scenarios for exploring the concept:

- ***Halting a combined arms attack (Desert Storm).***
- ***Securing territory (Bosnia).***
- ***Urban warfare against a CW/BW facility.***
- ***Extended offensive operations to attack enemy forces in an occupied nation.***
- ***Extraction of a brigade-size force.***
- ***Sea Dragon (USMC FOFAC concepts).***
- ***Neutralizing a deeply buried, hardened facility.***

JWFC was brought into the effort in early summer with six weeks to produce appraisal results. Because of this time constraint, JWFC examined only one scenario, extended offensive operations to attack enemy forces in an occupied nation.

The scenarios provided by the DSB, however, lacked detail. It was left to the participating teams to craft and articulate the relevant elements of each scenario. The JWFC team began creating these elements by laying the strategic- and operational-level foundations of the of the tactical-level wargaming scenario.[12] This step was especially important because at an initial DSB summer study conference some guest speakers questioned the direction of the DSB study. They maintained, for example, that the strategic and operational prerequisites for the DSB warfighting concept, such as dominance of the maritime and aerospace environments, would make the DSB warfighting concept irrelevant. Why put small, light land forces at risk when the targets could be attacked by naval and air systems? It was critical, therefore, for the JWFC team to construct the strategic- and operational-level dimensions of the selected scenario that would support credible tactical-level exploration of the DSB warfighting concept.

SCENARIO DEVELOPMENT

The creation of the strategic and operational-level dimensions of the scenario mirrored the process used by JWFC to develop scenarios and adversary campaign plans for major exercise events. This process produced the assumptions, initial conditions, and adversary force characteristics that would logically frame the pursuit of tactical-level missions. Alaskan terrain was used for its geographical diversity, but the geopolitical landscape was fictional. Acadia, the adversary force, invaded a province of Aleutia, a nation whose territorial integrity was vital to US national interests. The initial US response employed US naval and air forces to attack the invading Acadian forces. The simulation playbox was a portion of this scenario, the area of operations for a heavy Acadian corps. The corps was reduced in strength by US air and naval action to division-level strength. The Acadian corps dispersed its remaining units both to reduce its vulnerability to air and naval attacks and to establish control of the Aleutian province. In the JWFC study scenario, the Acadian forces were equipped with current US weapons systems and there were no viable Aleutian forces remaining in the area to support US operations.

Another critical portion of the scenario was the design of the US ground forces that were to use the DSB's warfighting concept. Here again, the DSB concept lacked the details necessary to

model and employ these forces. In a wargaming simulation, units and systems must be modeled with specific parameters: number of personnel, movement rates, sensor acquisition characteristics, weapons range, lethality, etc. In addition, the war gamer must employ the units using the appropriate doctrine—a mix of tactics, techniques and procedures (TTPs) unique to each type of unit. While a new technology may be exciting and potentially useful, in the end it must be coupled to appropriate military doctrine and missions. When the forces are a theoretical construct of the future, the war gamer must extrapolate current doctrine into the future and derive TTPs appropriate to the imaginary units' missions and capability. Unit organization, size, and employment tactics must accommodate the weapons and systems derived from the concept. In the case of radically new concepts, it is difficult to justify the mere patching of new weapons and systems onto existing formations and doctrine. These issues were also discussed at a DSB conference. The JWFC study team's solution was the creation of a new kind of unit, Brigade 2015.

Brigade 2015 was conceived as a strategically mobile and technologically advanced ground force. In this scenario, it was the ground-based exploitation element of the initial US air and naval response. The brigade was inserted into Aleutia by a mix of strategic and theater air assets. In Aleutia, its mission was control of key terrain and facilities and to attack Acadian forces that were mobile, perishable, and dispersed—targets not suitable for engagement by autonomously operating air and naval weapons systems. Brigade 2015 was dispersed into numerous teams within its area of operation. Each team, the brigade's basic combat element, was composed of 10 personnel and could move by foot or helicopter. The teams had immediate access to a theater-level tier of distributed information that provided sufficient intelligence for situation awareness but not detailed enough for targeting. For weapons targeting, each team relied on another set of locally controlled systems either organic to the team or provided by a team Unmanned Aerial Vehicle (UAV). Although the teams had some organic fire support capability, they avoided direct engagement with Acadian forces. Instead, they relied on long-range air support, arsenal ships or a UAV with a directed energy weapon to engage Acadian forces. Brigade missions would be limited initially to synchronized missions by a few of the teams. As the situation matured, the brigade would bring together its teams and transition to battalion and brigade-sized missions.

The scenario elements were then translated into Joint Conflict Model (JCM) database elements. JCM is a high-resolution training simulation that depicts military activities on a map-like video display. The simulation war gamer controls forces through orders and is presented information based upon the capabilities and actions of his assigned forces. Figure 2 summarizes the general scenario elements and displays the JCM simulation playbox (a portion of occupied Aleutia) with Acadian adversary forces.

SCENARIO VIGNETTES

Initially the JWFC team envisioned a single extensive war game scenario that included deployment, employment and sustainment of the brigade. During the design stage, the scope was quickly reduced because the JWFC team found that effort diverted to a broad treatment began to obscure the essential elements of the issue. Focus was restored by developing several employment missions that would be plausible missions for Brigade 2015 to undertake within the general scenario. Deployment and sustainment of the brigade, while obviously important, was dropped from the experiment. The team felt that the first critical test of the DSB concept was employment. Investigating the deployment and sustainment aspects of the concept would be necessary only if the concept could accomplish employment missions.

Eleven brigade team missions were developed that encompassed a spectrum of missions likely to occur within the general scenario. After examining the characteristics of each mission, the team selected four that effectively sampled all the characteristics present in the original eleven. The four missions were then fully developed into scenario vignettes. The selection process was similar to that used in designing analytical experiments around an anticipated response surface. Each vignette and the embedded mission characteristics were sufficiently diverse to give the JWFC team confidence that they would explore a representative range of environments and potential outcomes. The four vignettes, depicted in relation to the general scenario, are displayed in Figure 3.

General Scenario - Invasion of Aleutia by Acadia

- Invasion force consisted of a heavy corps ground force supported by fixed and rotary-wing air assets.
- US air and naval units conduct strategic and operational-level attacks. Air and maritime dominance established.
- Acadian force, dispersed throughout Aleutia, is consolidating its control and occupation.

Specific Scenario - Brigade 2015, a strategically mobile, technologically advanced ground force inserted into Aleutia.

- First land force follow-on to initial US air and naval responses
- Brigade dispersed throughout area of operations, is organized around small teams capable of either independent or synchronized operations.
- Brigade teams attack Acadian forces that are mobile, perishable and dispersed - targets not suitable for autonomously operating air and naval weapons.
- Teams avoid engagement with Acadian forces. Instead they locate and target Acadian forces for attack by long-range supporting fires and air support.

Scenario map of Acadian occupation forces - the "playbox" for the war game.

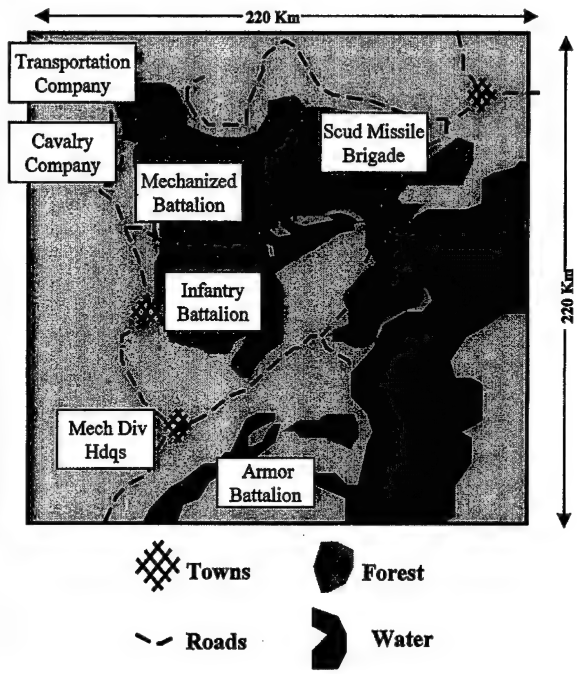


Figure 2. This schematic depicts the scenario used for the JWFC concept appraisal. The map shows the Acadian forces remaining in a sector of Aleutia after US naval and air attacks. There are no friendly Aleutian forces remaining in this sector. These forces comprised the adversary for the war game scenario vignettes.

VARIABLES

Another challenge was defining and measuring test variables. The JWFC study team spent a considerable amount of time wrestling with the problem of how and what to measure. One source of frustration was the attempt to use measurements that were very compelling from an analytical perspective but which were inappropriate to a wargaming environment. Another distraction was the consideration of measurements so detailed that they obscured the proposed warfighting concept.[13] Finally, the study team recognized that in wargaming, like many other undertakings, simplicity invokes clarity. Several dozen candidate measures were reduced to six measurements: four independent variables and two dependent variables.

At the same time, the JWFC team considered the methodology for manipulating the independent variables. Clearly, it would not be feasible to examine a large number of potential values. Yet, there was a desire to observe the response of the dependent variables to changes in independent variables. Typically, in sensitivity analyses, independent variables are allowed to vary nearly continuously but within a restricted, marginal domain. The JWFC appraisal, in contrast, allowed the independent variables to take on only one of two values. The domain, however, was very wide, representing order-of-magnitude changes in the variables. The four independent variables and their allowable domain values were:

- ***Mobility (how fast the teams could move)***—foot mobile ***or*** helicopter transport.
- ***Sensors (the ability of the teams to acquire and track adversary forces)***—basic (unit and weapons systems) ***or*** basic plus a reconnaissance UAV.
- ***Long Range Fire Support (fire support assets available in addition to the teams' organic weapons)***—four F/A-18 sorties and an arse-

Four Vignettes - snapshots of brigade operation that provide range of plausible mission environments and the context for examining warfighting concepts

- Defend Mining Area - 9 teams defend mineral mining area from Acadian attack
- Scud Hunt - 3 teams locate and destroy Acadian missile brigade
- Area Ambush - 9 teams ambush Acadian convoy
- Meeting Engagement -9 teams inadvertently contact Acadian battalion

Independent Variables

- Mobility - infantry or heliborne
- Sensors - basic (unit and weapons) or basic plus team UAVs
- Supporting Fires - 4 F/A-18 sorties and arsenal ship or armed UAV
- Sensor-shooter time - short (1 min.) or long (11 min.)

Dependent Variables

- Mission effectiveness
- Unit survivability

Location of mission vignettes within the general scenario.

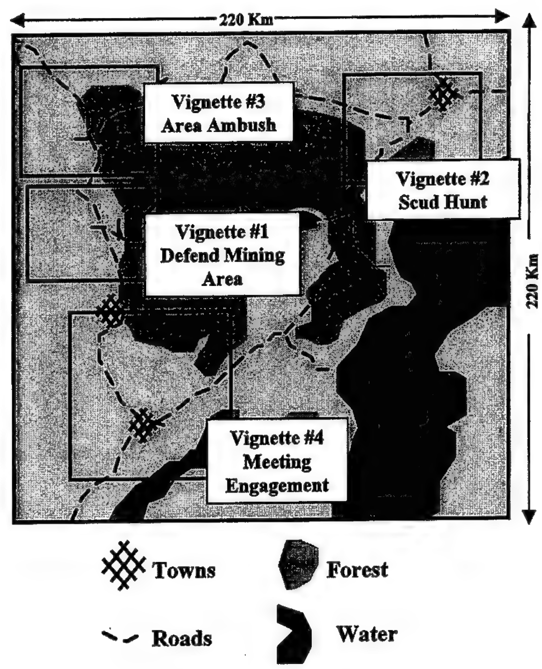


Figure 3. This schematic depicts the spatial relationship among the four scenarios. The four scenarios were treated independently—the outcomes in one vignette did not impact either side's behavior or resources in another vignette. Each vignette was wargamed several times using different values of the independent variables.

nal ship *or* four F/A-18 sorties and an armed UAV with a directed-energy weapon.

- ***Sensor-to-Shooter time (length of time needed to call for fire support after a sensor acquired a target)***—11 minutes *or* 1 minute (Note: Sensor-to-Shooter time only applied to on-call fire support; pre-planned fire support occurred at the designated time.)

The two dependent variables and their allowable ranges were:

- ***Mission effectiveness***—adversary personnel and systems killed or destroyed, normalized between 0 (none) to 100 (all).
- ***Unit survivability***—brigade team personnel and systems remaining, normalized between 0 (none) to 100 (all).

With four vignettes and four independent variables capable of exhibiting two values each, there are 64 unique combinations suitable for wargaming. The JWFC study team had neither the resources nor time to run each unique combination and reduced the test schedule to 26 runs. Some reduction was possible by analyzing the dependent variable characteristics. For example, the armed UAV had its own acquisition and tracking systems; therefore, it was seldom used in conjunction with a reconnaissance UAV. Also, because of the characteristics of the armed UAV, Sensor-to-Shooter time was always 1 minute if a brigade team had an armed UAV. The Sensor-to-Shooter varied only when the arsenal ship was used. Mobility varied only in the fourth vignette. The resulting test schedule is displayed below:

- ***Vignette 1:*** 2 runs, Sensors varied.
- ***Vignette 2:*** 6 runs, Sensors, Long Range Fire Support, and Sensor-to-Shooter Time varied.
- ***Vignette 3:*** 6 runs, Sensors, Long Range Fire Support, and Sensor-to-Shooter Time varied.

- *Vignette 4:* 12 runs, 6 runs, Sensors, Long Range Fire Support, Sensor-to-Shooter Time, and Mobility varied.

In addition to the two quantitative dependent variables, a qualitative measure of outcome was also developed. For each scenario vignette, an adversary and brigade commander's mission statement was created. The mission statements provided a tactical plan for both adversary and brigade war gamers and described the objective of each side in a specific vignette. More importantly, though, it defined mission success for each side. In hindsight, creation of a commander's mission statement was the most important element in the scenario design process. It gave purpose and discipline to each vignette by allowing the war gamers to plan and act as tactical unit commanders. During the test runs, while the simulation was recording the numerical data, the war gamers were recording their personal observations. Blending quantitative data and qualitative observations into one coherent account would not have been possible without the structure imposed by a mission statement. At test completion, the attainment of each side's mission statement was found to give the clearest measure of outcome, better than the quantitative measures of mission effectiveness or unit survivability.

Figures 4 through 7 display each of the four vignettes. Each figure contains an abbreviated description of the vignette, a tactical plan overlaid on the JCM graphic map, and a table which lists the run identification number with the independent variables.

EXAMPLES OF RESULTS

As previously described, test results were synthesized from quantitative data and qualitative observations. As enumerated in Table 1, the observations of the war gamers in relation to the accomplishment of the commander's mission statement were:

Acadian battalion-size force attacks Aleutian mining area defended by company-size force of brigade teams.

- Acadian mission is controlling terrain
- Brigade mission is denying Acadian access to area

Run	1	2
Mobility		
Infantry	X	X
Helicopter		
Sensors		
Standard	X	X
Team UAV		X
Long Range Fires Air Support		
F/A-18 (4 sorties)	X	X
Arsenal Ship	X	X
Armed UAV		
Sensor-shooter Time		
1 Minute	X	X
11 Minutes		

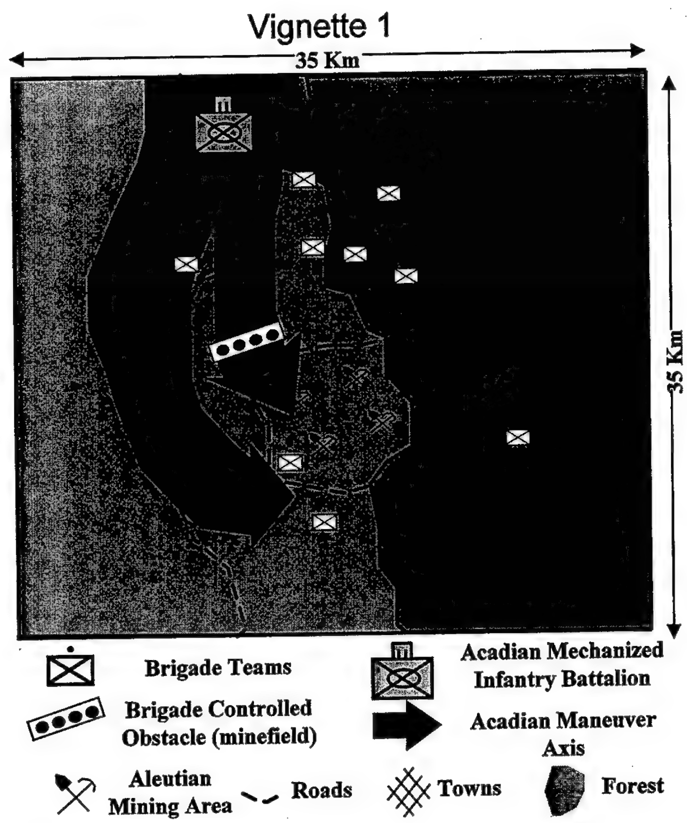
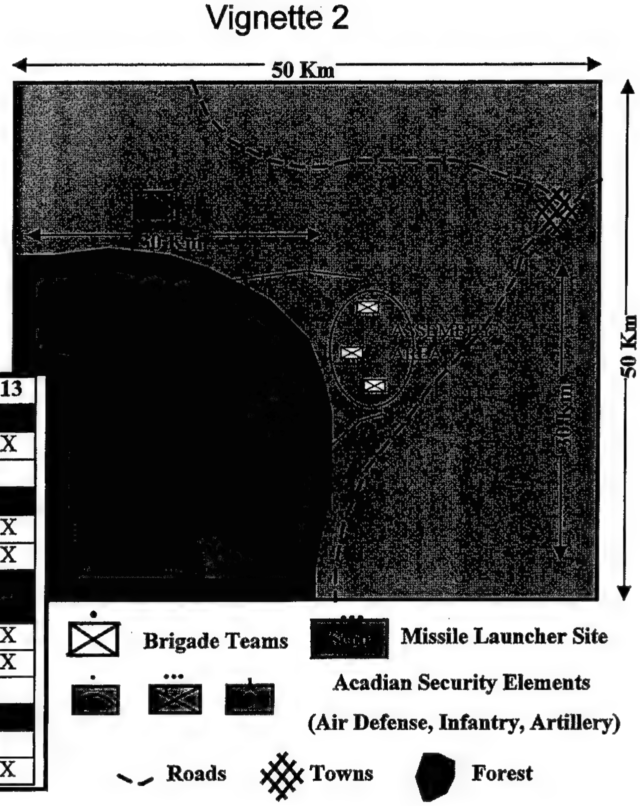


Figure 4. Vignette 1.

Platoon-size force of brigade teams locates and attacks a dispersed Acadian missile brigade.

- Brigade mission is reconnaissance and indirect fire engagement of missile launchers.
- Acadian mission is area security.



Run	3	5	7	9	11	13
Mobility						
Infantry	X	X	X	X	X	X
Helicopter						
Sensors						
Standard	X	X	X	X	X	X
Team UAV				X	X	X
Long Range Fires Air Support						
F/A-18 (4 sorties)	X	X	X	X	X	X
Arsenal Ship		X	X		X	X
Armed UAV	X			X		
Sensor-shooter Time						
1 Minute	X	X		X	X	
11 Minutes			X			X

Figure 5. Vignette 2.

- *For the 26 runs, brigade teams won 12 and adversary forces won 11 (based on mission statement; 3 were draws (neither accomplished mission).*
- *Brigade teams always won if they had use of the Armed UAV.*
- *Brigade teams never won if they had only the arsenal ship and standard sensors.*
- *Brigade teams won 4 and lost 2 (3 draws) if they had an arsenal ship and team UAV sensors.*

Quantitative results were presented in three formats. The first consisted of comparing quantitative measures of mission effectiveness and unit survivability within a specific vignette. Figure 8 displays one of these formats from Vignette 4. Note that the quantitative measures are generally consistent with the qualitative observations of mission accomplishment displayed above.

Another format for displaying data was comparing changes in an independent variable to the two dependent variables within like pairs of runs. For example, runs 3 and 5 were alike except for the value of the fire support variable. Run 3 used the armed UAV and run 5 had the arsenal ship (as explained previously, both also used four F/A-18 sorties). This was done for each independent variable, resulting in 8 total charts. Figures 9 and 10 display two of these charts, the data for the fire support variable measured against mission effectiveness and unit survivability between like-run pairs.

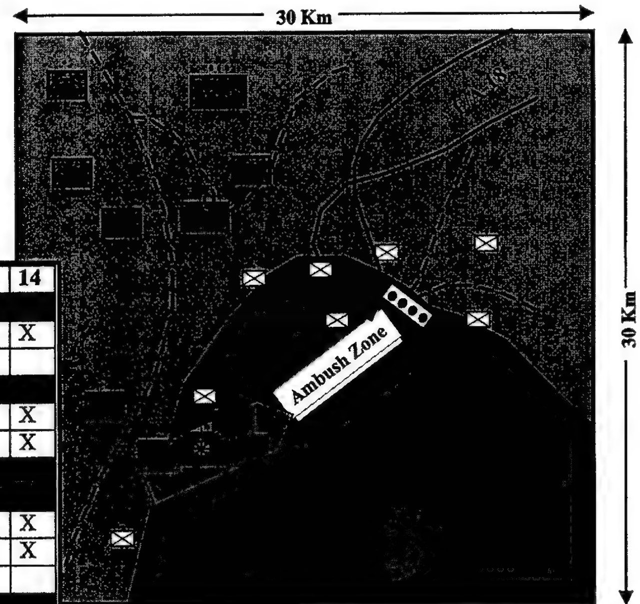
The variable-oriented data was also consistent with expected results, showing a positive relationship between "better" values of the independent variable and outcomes favorable to the US side. However, the value of this format was not in showing the relative sensitivity of an independent variable to outcomes in a specific mission category or vignette. Rather, it provided a confidence check of individual runs and the general methodology. Apparent anomalies were examined to determine their causes. For example, in the 9/11 run pair (Figure 9), the mission effectiveness measure went up when the arsenal ship was used instead of an armed UAV. This data was incongruent with other run

Company-sized force of brigade teams attacks an Acadian battalion moving along a highway.

- Brigade mission is to ambush moving Acadian forces
- Acadian mission is conducting a secure movement of a convoy.

Run	4	6	8	10	12	14
Mobility						
Infantry	X	X	X	X	X	X
Helicopter						
Sensors						
Standard	X	X	X	X	X	X
Team UAV				X	X	X
Long Range Fires Air Support						
F/A-18 (4 sorties)	X	X	X	X	X	X
Arsenal Ship		X	X		X	X
Armed UAV	X			X		
Sensor-shooter Time						
1 Minute	X	X		X	X	
11 Minutes			X			X

Vignette 3



Roads

Forest

Brigade Teams

Brigade Controlled Obstacle (minefield)

Acadian Support Elements (Air Defense, Rocket Artillery, Artillery)

Acadian Convoy (Transportation, Armored Calvary units)

Figure 6. Vignette 3.

pairs. Examination of the vignette observations from the war gamers, however, quickly revealed an explanation. In run 9 the brigade teams were able to quickly accomplish their mission, destruction of three Scud launchers, with minimal engagement of the Acadian unit's security forces. In run 11, however, the brigade teams only destroyed two of three launchers but inflicted a considerable amount of collateral damage to other elements of the Acadian missile unit. Since the quantitative measure of mission effectiveness counted all elements of the Acadian unit, the measure was higher even though the war gamers graded run 11 as a draw—neither side met its mission.

CONCLUDING OBSERVATIONS ABOUT WARGAMING

The JWFC study team knew that they were employing a hybrid approach by combining techniques from the training and analytical domain but when combined, might exhibit unique characteristics and challenges. While some of these characteristics and challenges were anticipated before the effort began, many were discovered through false starts, dead ends and unsuccessful runs. Some, no doubt, were missed and await discovery by others. Nevertheless, a few of the team's observations deserve consideration.

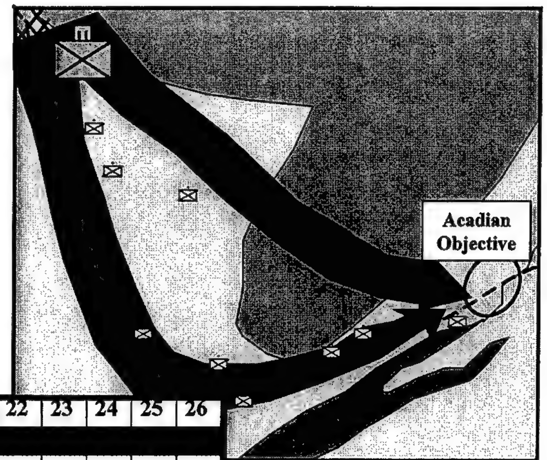
Wargaming simulations, no less than analytical models, generate enormous quantities of numerical data. It is tempting to manipulate and interpret wargaming data using the same techniques so useful for analytical models. However, quantitative data from wargaming simulations must be viewed within the context of the test.[14] Any conclusions derived from the data must acknowledge the characteristics of wargaming-based appraisals when compared to more typical analytical experiments. Because the central focus of wargaming is the human

Company-sized force of brigade teams encounters an Acadian battalion moving to an objective.

- Brigade mission is force protection and then defeat of Acadian forces.
- Acadian mission is secure movement to its objective.

Roads
Towns
Water
Forest

Vignette 4



Run	15	16	17	18	19	20	21	22	23	24	25	26
Mobility												
Infantry	X	X	X	X	X	X						
Helicopter							X	X	X	X	X	X
Sensors												
Standard	X	X	X	X	X	X	X	X	X	X	X	X
Team UAV				X	X	X				X	X	X
Long Range Fires Air Support												
F/A-18 (4 sorties)	X	X	X	X	X	X	X	X	X	X	X	X
Arsenal Ship		X	X		X	X		X	X		X	X
Armed UAV	X			X			X			X		
Sensor-shooter Time												
1 Minute	X	X		X	X		X	X		X	X	
11 Minutes			X			X			X			X

Acadian Infantry Battalion

Acadian Maneuver Axis

Brigade Teams

Figure 7. Vignette 4.

decision processes, each instance of a war game is unique.[15] In wargaming, the essential assumption for sensitivity analysis that demands everything but a single variable be held constant is seldom met. For example, in the paired data above, the paired runs were alike but not identical. Although the starting conditions were identical except for the value of the fire support variable, once the runs started each team had a different set of decision paths available. Each side pursued its mission based upon the assets it had available and its perception of the opponent's reaction to its decisions. Therefore, a vignette should not be conceptualized as a linear sequence of activities through time, a single thread forming a decision line. Rather, it is a multidimensional decision space with decision nodes, branches and sequels forming a response surface. Between like pairs of runs, some of the branches and sequels were similar but each decision space was unique. Therefore, it is erroneous to assert that difference in run outcomes (dependent variables) between like pairs is the sole result of changes in the independent variables. The pairs, while similar, are rigorously speaking, single point samples from different response surfaces. This is typical of most wargaming but leads to additional complications when attempting to explain outcomes.

Many models, including war games, employ stochastic techniques to compute such things as sensor acquisition, kills, etc. In such cases, an observer cannot have high confidence that a single sample of an outcome is close to the expected value. To achieve a higher level of confidence, war game orders are saved and the model is run numerous times. Theoretically, this will produce a series of outcomes whose mean approaches the expected value. This technique is not valid when human decision processes form a central part of the effort because it does not capture the branches and sequels that might have been generated by differing values

Table 1. Summary of Tests

Run #	1	2	3	5	7	9	11	13	4	6	8	10	12	14	15	16	17	18	19	20	21	22	23	24	25	26
Vignette #	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4
Mobility																										
Infantry	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
Helicopter																					X	X	X	X	X	X
Sensors																										
Standard	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Team UAV		X				X	X	X				X	X	X				X	X	X				X	X	X
Fires																										
F/A-18	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Arsenal Ship	X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X
Armed UAV			X			X			X			X			X			X			X			X		
Sensor-shooter Time																										
1 Min	X	X	X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X	
11 Min					X			X			X			X			X			X			X			X
"Winner"	A	A	US	A	A	US	?	US	US	A	A	US	US	?	US	A	A	US	US	A	US	A	A	US	US	?

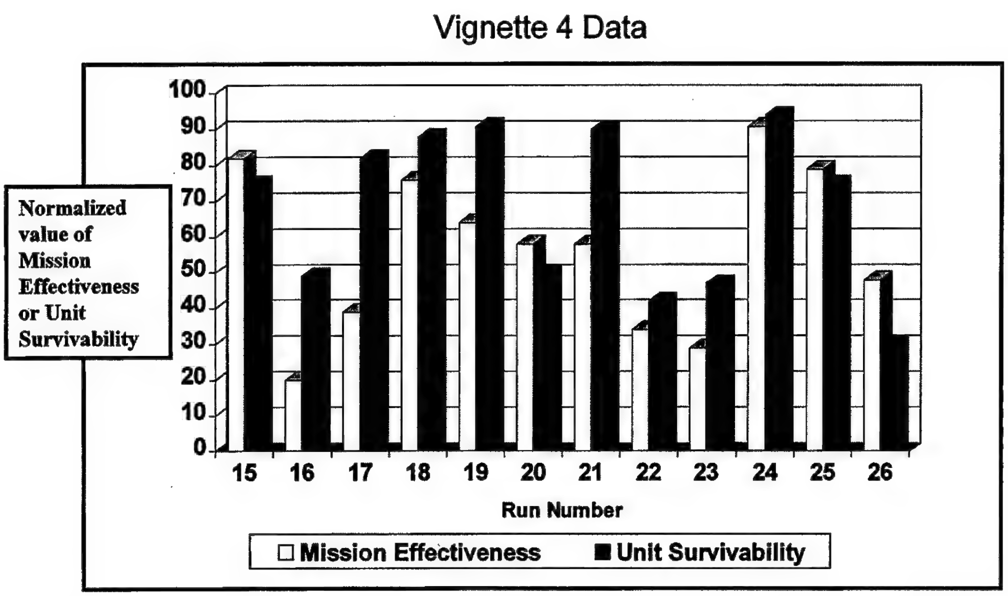


Figure 8. The chart shows data from Vignette 4. Mission effectiveness was measured as the amount of adversary personnel or systems killed or destroyed, normalized between 0 (none) to 100 (all). Unit survivability was the amount of brigade team personnel and systems remaining, normalized between 0 (none) to 100 (all).

of the stochastic event. A commander, for example, may alter an attack (a war game order) if the results of an air attack (a stochastic event) were exceptionally effective. One compensation technique is to examine each scenario vignette's decision space and identify those nodes whose branches are primarily determined by results from stochastic events.[16] From that node, then, additional runs can be conducted to see if significantly different branches and sequels exist. In the JWFC study effort, we identified one such node, the effect of minefield on Acadian movement during the ambush in Vignette 3. In this instance, the effectiveness of the minefield changed the movement rate through the brigade teams' kill zone. It did not, however, cre-

Data Organized by Variable

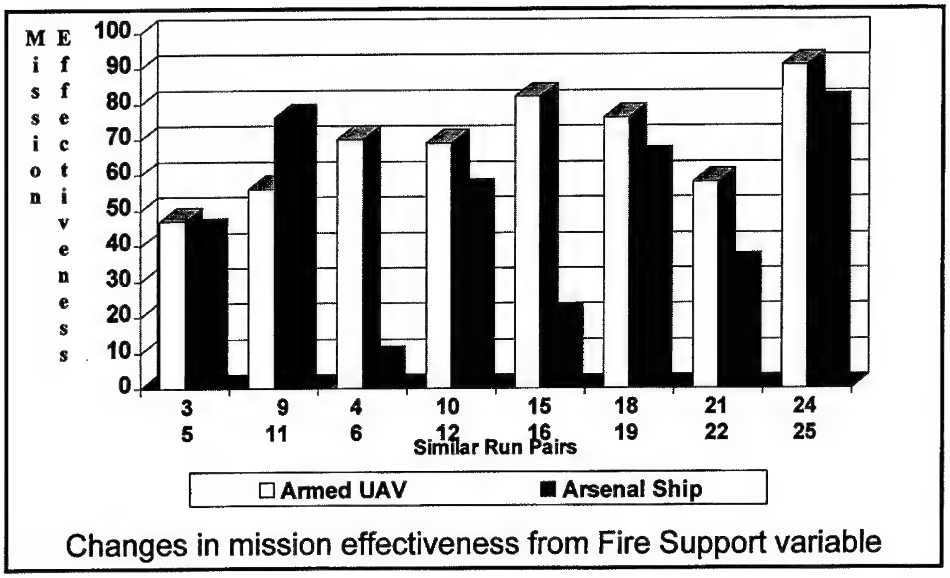


Figure 9. The chart shows the value of mission effectiveness from vignette pairs in which all the independent variables except fire support were treated equivalently.

Data Organized by Variable

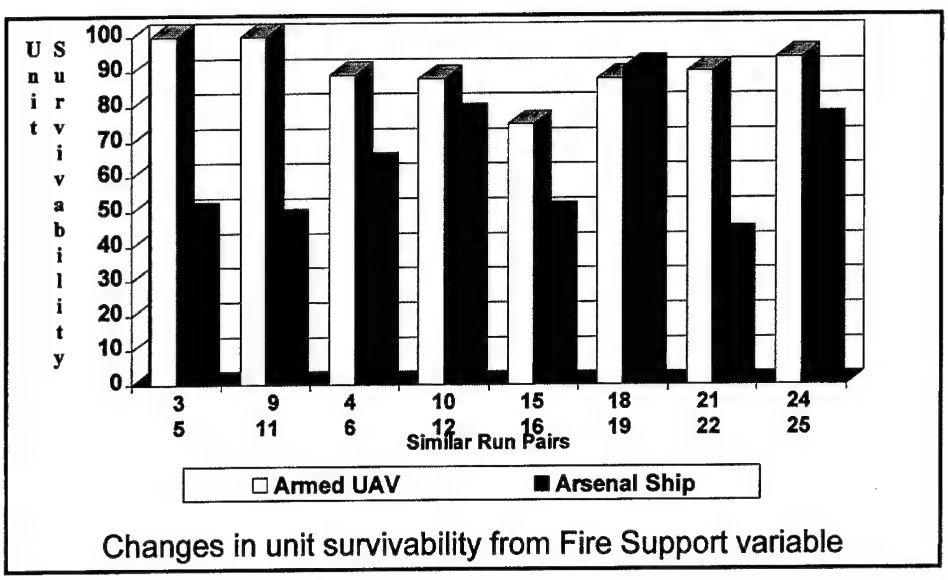


Figure 10. The chart is similar to Figure 8 except that changes in unit survivability are plotted against changes in fire support for equivalent run pairs.

ate significantly new decision paths. Exploring significant nodes and possible decision paths is laborious but it can be minimized through exercise design. In training events, wargaming scenarios are usually broad in scope and time. If wargaming is being used for appraisals, then

the scenario should be reduced to a manageable number of small, focused scenario vignettes each containing a small set of possible decision paths.

Compared to typical uses of analytical models, wargaming-based concept appraisals may be limited in depth and detail. They do, however, exhibit one compelling characteristic, the inclusion of human decision processes. To be successful, wargaming appraisals should:

- ***Be used when human decision processes are critical components of the study issue—created from the perspectives of a commander and staff.***
- ***Have a small number of variables—simplicity provides clarity.***
- ***Be focused—design using several specific, limited scenario vignettes.***
- ***Be linked to appropriate tactics, techniques and procedures—simply grafting new weapons into existing doctrine is not appropriate.***
- ***Present synthesized results—combine expert observation with quantitative measurements.***

Results of wargaming-based appraisal effort should be used with discretion. Because they lack the detail of analytical models, they are not appropriate tools for proving the validity of concepts or weapons systems. Rather, they should serve as method of obtaining insight. This insight can then point to areas where more detailed analysis or assessment may be appropriate. Some examples of appropriate use of wargaming appraisals:

- ***Exploring technology-based concepts if the primary interest is the linkage or interaction between the capability of systems and the pursuit of military missions.*** Wargaming can investigate how new employment patterns (and adversary reactions) emerge from human decision processes that respond to changes in the capabilities of weapons systems.
- ***A filter for new doctrine, especially those relying on information-based systems or capabilities.*** Wargaming can be used to anticipate the decision space—nodes, branches and sequels—of new tactics, techniques and procedures and then map the range of plausible outcomes under various scenarios.
- ***Establishing parameters for operational field tests of new weapons systems or doctrine.*** Wargaming can be used to help design the scenario elements, range space, or size of an impact area needed to test a new weapons system under realistic mission conditions.

Because of the need to explore multiple decision paths, wargaming requires a large number of talented military professionals. The JWFC study relied on fourteen individuals in the design, preparation, execution and appraisal stages of this effort. Four critical talents were needed and all team members were experts in at least two of them.

- *Joint warfighting and wargaming experts*—designed and executed scenario vignettes, created brigade team composition, weapons and doctrine, and composed the commanders' mission statements.
- *Opposing force specialists*—created the details for the experiment's scenario, a logical opposing force campaign plan, and individual supporting missions.
- *Operations researchers*—provided the overall experimental design and synthesis of data and observations.
- *Technical support personnel*—built the simulation database and configured the war game.

Of all the talents, the most critical was joint warfighting and wargaming. This type of effort cannot be conducted without war gamers who are proficient in current and emerging joint and service doctrine, tactics, techniques and procedures. In addition, the war gamers must be well versed in the characteristics of the wargaming model. Every war game has different capabilities and limitations. Professional war gamers can compensate for the inherent inaccuracies and limitations of the simulation without sacrificing operational military validity.

In conclusion, the challenges confronted in using a wargaming simulation for concept appraisal are significant. The effort, however, can be very productive because it is a methodology that is different from the use of analytical simulations. The methodology used by JWFC blended techniques from training-based wargaming events with those used for analytical experiments. Often people assume there is symmetry between simulation-assisted exercises and analysis if they both use computer models. Such an assumption, which focuses on the tool instead of the task, can lead to flawed methodologies. Understanding the difference, though, can provide a useful tool for military operations research.

ENDNOTES

[1] Throughout summer 1996, the DSB effort engaged numerous participants organized into several teams, each employing a variety of methods to investigate this technologically based warfighting concept. The JWFC study results were presented to DSB Team 2, Territory Control, in August 1996.

[2] Extracted from the *Memorandum for Chairman, Defense Science Board* [8]. To frame the environment and characteristics of the warfighting concepts, the DSB postulated seven different scenarios. Because of time and resource constraints, the JWFC effort was limited to examining one scenario.

[3] The JWFC appraisal team was composed of 1 military and 14 contractor personnel from JWFC: Maj Greg Brouillette, Robert Chapman, Steve Corner, Earl Eaddy, Doug Failor, Robert Fall, Andre Fryer, Dave Hastedt, Nate Hilliard, Ray Lingo, William Pattison, Larry Rautenberg, Mark Rose, Larry Stratton, and John Zanelli.

[4] Another reason for limiting the reader's exposure to the study is to preserve the confidence of the original customer. This is the same policy JWFC has towards its exercise customers. At the end of an exercise, a Commander's Summary Report is provided in confidence to the exercise sponsor. It is not shared with superior, lateral, or subordinate organizations. Furthermore, the JWFC team provided appraisal results devoid of conclusions or recommendations. It was left to the DSB to derive insights and inferences from the data.

[5] The basis for the JWFC concept appraisal process was based on the Joint Exercise Life Cycle (JELC) as described in the *Joint Training Manual*, [6, Ch VI]. The JELC is a disciplined process to design an exercise that links mission essential tasks to training objectives and ultimately simulation inputs and outputs. The JWFC study team created the depicted analogue of the JELC for their wargaming study. Like the JELC, the appraisal effort is viewed as a process composed of discrete tasks or products linked together and organized into several progressive stages.

[6] The JWFC concept appraisal is different from traditional assessment and analyses. While concept appraisal may provide insights, it does not have the fidelity of analyses or the comprehensiveness of assessment. Compared to concept appraisal, assessments are more comprehensive endeavors whose results are often used for evaluation of macro issues such as force structure or war plans. Analyses more often evaluate micro issues through detailed reductions of complex systems into smaller elements; e.g., trade-off studies of a weapons system's performance characteristics.

[7] Although more restrictive than the approved definitions, they are consistent with DoD community usage where the terms "model," "simulation" and "war game" are often used interchangeably. In reality, they have different meanings. The *Glossary of Modeling and Simulation (M&S) Terms* [5] defines war game as "a simulation game in which participants seek to achieve a specified military objective given pre-established resources and constraints; for example, a simulation in which participants make battlefield decisions and a computer determines the results of those decisions." Model: "a physical, mathematical or otherwise logical representation of a system, entity, phenomenon, or process." Simulation: "a method for implementing a model over time."

[8] This process was recorded after the effort and depicts both the elements the appraisal team accomplished and those that were truncated because of the lack of time. Because of the time constraint, some elements, such as a Memorandum of Agreement, were not attempted. Others, such as verification and validation, were combined.

[9] Verification in the appraisal process focuses on the conceptual model of the warfighting

concept—the database and simulation attributes and their ability to replicate the relevant elements of the concept. This includes the creation of new objects and modifying existing objects as surrogates. For example, in the this study an armed UAV was created by modifying the attributes of an already existing aircraft. Overall, this activity is more verification of the design of elements than code. Both are described in *VV&A Recommended Practices Guide*, [10, Ch 1].

[10] Validation follows verification but is more focused on results from practice runs of the scenario. Validating data and model functionality for concepts, tactics, and technologies that have yet to be fielded operationally (or even tested) is an effort to check for reasonable behaviors and results. It is not an effort to define the accuracy of the results. The best one can hope for is selective insights into a few relationships, not predictive results, marginal values, or tradeoffs. Again, refer to *VV&A Recommended Practices Guide.*

[11] The warfighting concept explored by the DSB Summer Study was similar to ideas present in *Joint Vision 2010*, the Chairman's "... operationally-based template for the evolution of the Armed Forces for a challenging and uncertain future" [7]. Like the DSB Summer Study, *Joint Vision 2010* explores future concepts for military operations. There are, however, significant differences. While *Joint Vision 2010* includes all the Services, the DSB Summer Study focused on land forces. Both examine relationship between information superiority, technological innovations and operational concepts. But again, *Joint Vision 2010* has a wider, operational focus whereas the DSB study was technologically oriented to more specific applications.

[12] Refer to *The Universal Joint Task List (UJTL)* for an explanation of: the strategic, operational, and tactical levels of war; the process used to analyze a mission into a series of related tasks; and identifying mission essential tasks and assigning appropriate conditions and standards. Understanding the UJTL approach is essential to wargaming.

[13] The challenges faced by the JWFC study team were not unique. Battillega and Grange in *The Military Applications of Modeling* describe these difficulties. "The challenge and art of modeling is the representation of primary relationships, where the question of relevance is entirely dependent on the purpose for which the model is used." [1, page 7] And also: "The model must ultimately resolve the conflict between the desired level of modeling detail and uncertainties which exist in basic input data. Sometimes the resolution transfers the burden to the analysts in the sense that they can either extrapolate details into basic data so that they can generate appropriate model inputs, or attempt to interpolate between model results focused too imprecisely to produce desired analysis results." [1, page 9]

[14] Although presented in a slightly different context, Robert Elberth makes a cogent argument that, with respect to detail, fidelity, realism and accuracy, "... reality doesn't exist within the computer." [4, page 26] Many simulations, such as the one used for this appraisal, JCM, can portray very detailed combat activities (e.g., the field of fire of an infantry rifleman in an urban environment based on the interaction between weapons range and line-of-sight limitations due to obstruction). Detail, however, does not imply validity. "There are real risks—potentially measured in lives lost—to pushing detail and causal relationships below the data for which we have real data."

[15] In a training event, each instance of an event is unique—it can be done only once. One of the most powerful tools in quantitative analyses is the ability to run an experiment numerous times to derive expected outcomes, establish the range of possible outcomes, and modify variables for sensitivity analysis. The technique is not possible when real human decision processes are used. The limitation is both practical and theoretical. Sim-

ulation events using real commanders and staffs are expensive and time consuming. Most joint force commanders cannot assemble their staffs and components together for a training event more than once a year. Even then, the event must be carefully tailored and reduced in scope to focus on the most pressing objectives. Even if it were possible to engage these staffs more often, theoretical limitations apply. Commanders and staffs learn. Playing the same scenario many times with the same group is not the same as running a simulation many times. In a strict sense, human decision processes are uncontrollable variables. Whenever they are part of the experiment, each instance of the "same" experiment is really a single sample from different universes. This characteristic invalidates the application of most statistically based sensitivity analyses.

[16] The concept of a commander's decision space is critical to wargaming. For a concise description of how decision spaces, courses of action and planning horizons relate to wargaming see *Time and Command Operations: The Strategic Role of the Unified Commands and the Implications for Training and Simulations.* [11, pages 31–35] The authors of this IDA report were focused at the unified and sub-unified command level. However, the same attributes, appropriately scaled, apply to tactical-level decision processes. Although the JWFC study was conducted before their document was written, it articulates many of the experimental design concepts applied by the JWFC appraisal team.

REFERENCES

Battilega, A. K. and J. K. Grange, *The Military Applications of Modeling*, AFIT Press, Wright-Patterson Air Force Base, Ohio, 1981.

Cohen, William S., *Annual Report to the President and the Congress*, April 1997.

Defense Science Board Test Plan, internal document prepared for Defense Science Board Summer Study, Joint Warfighting Center 1996.

Elberth, Robert, "Technical Forum—Openers," *Phalanx*, Vol. 29 No. 3, September 1996.

Glossary of Modeling and Simulation (M&S) Terms, Under Secretary of Defense (Acquisition and Technology), May 1997 (Draft).

Joint Training Manual for the Armed Forces of the United States, CJSM 3500.03, 1 June 1996, Joint Staff Washington, D.C. 20318-0400.

Joint Vision 2010, Chairman of the Joint Chiefs of Staff, Washington DC (Pamphlet).

Memorandum for Chairman, Defense Science Board, Under Secretary of Defense (Acquisition and Technology), March 15, 1996.

Universal Joint Task List Version 3.0, 13 September 1996, CJCSM 3500.04A.

Verification, Validation, & Accreditation Recommended Practices Guide, Office of the Director of Defense Research and Engineering, Defense Modeling and Simulation Office (DMSO), November 1996.

Worley, D. Robert, Michael H. Vernon, and Robert E. Downes., *Time and Command Operations: The Strategic Role of the Unified Commands and the Implications for Training and Simulations*, Institute for Defense Analysis, October, 1996 (Final Draft).

Concept Exploration on the Virtual Battlefield

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ABSTRACT

This paper reports on the use of virtual simulation for concept evaluation. It focuses on excursions conducted at the Institute for Defense Analyses (IDA) Simulation Center for the 1996 Defense Science Board (DSB) Summer Study on Tactics and Technology for 21st Century Military Superiority. These excursions engaged a slice of a 2015 battlefield portraying only the targeting elements of two small teams (2–3 men each) plus an intermediate headquarters and a task force headquarters. The exercise was divided into excursions designed to investigate combat effectiveness resulting from parametric variations in small team size and composition, mission, organic sensor capabilities, and remote sensor suites. The teams interfaced with a synthetic battlefield, visually through 3D visualization portals and electronically through sensor and communications interfaces. Future doctrine was initially developed and incrementally changed from lessons learned during the excursions. The project produced results on the evaluation of battlefield concepts and emerging technology and on the evaluation of advanced distributed simulation's utility for analysis.

KEYWORDS

Advanced distributed simulation, virtual, concept evaluation, synthetic battlespace

INTRODUCTION

The evaluation of concepts is challenging to the analysis community because of the difficulty in *optimizing* the effects of future technology, doctrine, organization, or training. Evaluation of concepts involving small units on the battlefield is particularly difficult. Traditionally, analysis has been performed with constructive models and simulations. However, analysts know that behavioral algorithms in constructive models are suspect for examining future concepts, especially those involving phenomena not validated in the models. Such phenomena include information dominance or military operations against new threats. Virtual simulation may provide a new approach to concept evaluation. Interesting aspects of this approach include the use of "human-in-the-loop" (*virtual*) simulation and a synthetic battlespace (distributed, entity-based, and real time within a realistic environment). It was tested as a proof of principle in the analysis of concepts and technologies investigated by the 1996 DSB Summer Study. A description of the DSB analysis needs and the scenario developed for responding to these needs, a description of the virtual simulation design and excursions, and finally a presentation of analysis of the observations with some results about virtual simulation and the synthetic battlespace in support of concept evaluation is provided.

CHALLENGES FOR CONCEPTS MODELING

Army acquisition policy (DA Pam 70-3) describes concepts as key components of top down cycle guidance. Warfighting concepts based on future threats and technological forecasts provide a means for identifying and analyzing future required capabilities.

A cursory review of the literature on military modeling (e.g. Battilega & Grange, Bracken et. al., and Przemieniecki) reveals surprisingly little discussion on the modeling of concepts. This could be indicative of a belief among analysts that there is no difference in modeling concepts vice modeling the current state. The author's experience indicates that current modeling practices assume that future concepts are incremental variants of current warfighting capabilities and therefore can be modeled by incrementally varying current models.

The concepts explored by the 1996 DSB Summer Study on Tactics and Technology for 21st Century Military Superiority and discussed in this paper were not incremental variants of the current state. Rather they were "quantum leaps" from the present into the future. How does one analyze such future concepts?

The analysis of concepts requires that we think about the limits of conceptualization. [Sowa] discusses the incongruity of the continuous aspects of the real world with the discrete nature of conceptual structures for artificial intelligence. This is one challenge to analyzing future warfighting concepts. For example, the DSB concepts were discontinuous with current doctrine, technologies, and organizations. The use of existing continuous aggregated constructive simulations may add no value to understanding these concepts since these simulations have no validity in replicating

OR METHODOLOGY: Design of Experiment, Virutal Simulation in Analysis

APPLICATION AREA: Concept Evaluation, Human Performance, Process Analysis, System Specification

future worlds. Indeed, the number of simulations available to address information technology issues in current operational context is limited. Many constructive simulations are simply incompatible with the operational impacts of new information based technologies and cannot be configured rapidly to accommodate new doctrines and organizations.

A CONCEPT OF SMALL UNITS ON A FUTURE BATTLEFIELD

The DSB focused "... on the concept of making relatively small and rapidly deployable forces (or teams)—specially equipped, trained, and supported by remote sensors and weapons—able to accomplish missions heretofore only possible with much larger and massed forces."

The DSB considered concepts where battlefield tasks are redefined so that the infantryman's mission of "closing with and killing the enemy" was changed to "managing remote sensors in the detection, classification, identification of targets, and surviving." These concepts required higher level command to "tag and track" targets for optimal engagement by precisely guided, remotely-based indirect fire. They also included the idea of empowerment—giving the soldier the information he required whenever he asked for it, and consequently giving him increased authority in his actions.

Technologies occupying a central position in the DSB study included assured stealthy communications such as digital cellular; a global information infrastructure including a common grid reference (geolocation, terrain, features), connectivity (reliable, low probability of intercept, voice, data, & video), and database fusion and analysis; massive numbers of remote sensors such as micro-UAVs and unattended ground sensors; massive availability of remotely and precisely delivered indirect fires such as arsenal ship or intelligent minefields; stealthy vehicles such as all electrical for survivable mobility; and "tagging and tracking" technologies such as micro-electromechanical systems (MEMs) or micro-UAVs. The DSB Summer Study also explored additional concepts and technologies not discussed here. Future warfighting requirements will depend on regional situations that vary greatly on missions, geo-political considerations, and geography.

The changing role of warfare analysis is that while monolithic Lanchester based models might be defended for analyzing cold war scenarios where a Soviet threat was poised to thrust massive numbers of tanks through NATO forces, they cannot be defended for analysis in the emerging international security environment. Geographically, defense concerns are now more globally diffused. Regional conflict implies increased variability in threat capabilities and includes the idea of an asymmetrical threat where low technology capabilities are leveraged against high technology vulnerabilities. Missions assigned to theater forces are of a broader spectrum including operations other than war. Also, technological capabilities are more information-based, enabling improved warfighting capabilities such as massing fires vice massing forces. All of these factors indicate the need for improved capabilities for analysis.

Representative analyses were conducted by different organizations for the DSB including the following topics.

- The impact of employing small teams and managing fires.
- The required time line for indirect fires.
- Base case and effect of expanding situational awareness and creating tracks between teams.
- Effect of direct control of UAV sensors by team and insight on ground-based cooperative engagement capability.
- Impact of mobility and sensor capabilities on team performance.
- Mobility impact on effectiveness of teams, plus helicopter survivability.
- Effect of better situational awareness of weapon mix, kills, and losses.

This article is concerned with the first of these analyses which was unique in its focus on the soldier and on its application of simulation type—virtual simulation.

EXPERIMENTAL DESIGN

[Ackoff] describes the following roadmap for the research process:

1. *Formulating the problem*
2. *Constructing the model*
3. *Testing the model*
4. *Deriving a solution from the model*
5. *Testing and controlling the solution*

6. *Implementing the solution*

Each step of this roadmap is addressed in the sections below. However, there are important aspects of the experimental design that require elaboration and qualification.

The first aspect is that this was a "proof-of-principle" effort. The experiment was designed to accommodate many different variables such as different numbers of sensors and weapons with varying performance characteristics, different organizations, different doctrines and tactics, different terrain environments, and different team equipment sets. We did not attempt a full factorial experiment in an effort to isolate variables to which combat results might be most sensitive nor did we fully control the solutions from the experiment. For example, only eleven excursions were executed.

Notwithstanding, we followed an approach that has been promoted by [Landauer and Nielsen] called User-Centered Design or Usability Engineering in which the usability of a system was emphasized over its technical specifications. In doing so, we relied on the powerful cognitive capabilities of our "usability testers" for resolving the complexities that result from having to deal with so many variables and so many unknowns that accompany the exploration of concepts. In this approach, Nielsen describes a moderately different model in the design of an experiment.

> *Pick existing user interfaces. Subject them to a simple user test by defining some typical test tasks and observe users as they try performing the tasks with the system. Where problems are found resolve them through iterative design.*

The second aspect is the validation of the simulation design. It was believed that the experiment required a scenario that would provide different features (environmental, time-distance, logical consistency in events, . . .) and would support a list of functions (battlefield surveillance, requests for fire, management of sensors, . . .). The simulation needed to support a scenario that stimulated future warfighting processes. The experiment used terrain and entities developed for Synthetic Theater of War–Europe (STOW–E) in October 1994. Although we had access to the more robust terrain data bases (dynamic objects, weather, smoke, etc) being developed for STOW 97, we decided to use STOW–E databases instead because of their proven stability. Subject matter experts in the experiment team determined that the STOW–E databases were credible for the applications envisioned for the virtual experiment. As with most validation efforts, a decision was reached on the degree of validation that could be afforded vis a vis the benefits expected from the experiment. This decision included scoping the experiment so that some simulation capabilities such as the resolution of the synthetic environment would not be required for the success of the experiment. It was known but accepted that the coarse resolution of terrain would impact conclusions about small team survivability (e.g. impact on line of sight). Rather than opt for higher resolution synthetic terrain, we chose to exclude survivability of small teams as an issue for our scenario design (i.e. the synthetic terrain stability decision above). In addition to the validation of synthetic forces and environments used in the experimental design, validation of performance characteristics of weapons and sensor systems was conducted through liaison with authoritative experts from OSD or the Services. Concepts from the Marine Corps Sea Dragon and the Army's Army After Next Program were used to generate initial battlefield processes for examination. Finally, the simulation design was reviewed by selected members of the DSB panel periodically during its development to assure that the experiment would demonstrate what was expected of it.

The third aspect is the question of why the experiment could not have been run in an aggregate level constructive simulation. In the past, aggregate level constructive simulations have been used because of their ability to run faster than real time, allowing frequent variable value changes for sensitivity analysis. However, Davis and Blumenthal provide illustrations where "aggregated models are invalid [with respect to] phenomena omitted or buried [such as] command-control processes, tactics, ... and other "soft factors' . . . ." Further, Dreyfus raises questions with respect to whether computers will ever be able to process information of certain cognitive behaviors, pointing to a growing body of evidence that human and mechanical information processing proceed in entirely different ways (e.g. learning, vision, natural language understanding, problem solving, and pattern recognition). In other words, human behavior is difficult to model. General Larry Welch, retired Air Force Chief of Staff has stated on occasion, "Constructive simulations model the past while the past is

not a good predictor of the future," noting further that the range of warfighting capabilities and scenarios is becoming increasingly wide for both the United States, its allies, and its potential foes. Nonetheless, the "entity-based" (vice aggregate level) constructive ModSAF proved crucial to the success of this virtual experiment. ModSAF enabled the interoperability of humans, their mission equipment, and the experimental components, including the simulation. It also provided the mechanism for incorporating future equipment design.

Finally cost of a virtual simulation is an issue. The project was given a specific amount of money, much of which was used for investment in equipment that would later be used for other analyses and much of which was paid for DSB activities that were independent of the virtual experiment. It is difficult to put an exact dollar figure on the cost of the experiment. Within the current state of the art, systems engineering is a costly aspect of initiating virtual simulations. However, the author believes this aspect of cost should be considered as transitory. Dramatic improvements in processing and communications and the evolution of standards in advanced distributed simulation promises to reduce costs over the near future. For example, STOW 97 used $5,000 Pentium workstations to drive ModSAF and synthetic environments, where $35,000 SGI workstations were required for STOW–E. If Moore's Law continues to prevail through next year, $2,500 workstations may do the same job twice as well. Moreover, initial testing of STOW has already demonstrated that organic C4I systems (AFATDS, MCS-P, GCCS or JMCIS, and CTAPS) can be integrated effectively with a simulation system. Further, it is clear that opportunities exist for STOW in the improvement of inefficiencies. The STOW technologies that include the use of artificial intelligence, natural language interfaces, and other labor saving techniques should facilitate the reduction of manpower in future simulation design. In other words, the state of the art is moving rapidly towards a simulation infrastructure that will support the development of experiments requiring less systems engineering. On the other hand, analysis using virtual simulation should be expected to be persistently more costly in manpower per unit run time period than analysis using constructive simulations. In this experiment, we used seven individual combatants, four observers (two operational and two behavioral), and six controllers. Other experiments will require more or less depending on the nature of the problems under investigation. When making such comparisons, it is astute to recognize that there are some important issues that best can be analyzed through virtual simulation, particularly usability or interface problems. In comparison, a field experiment should be expected to cost much more than a virtual experiment in examining some issues involving human performance and provide much less flexibility. To confirm such beliefs [Worley, et al.] reported that the United States Atlantic Command's AGILE PROVIDER 94 Exercise cost $48 million, while the United Endeavor 95 exercise, using the Joint Training Confederation of constructive simulations cost only $3.4 million or about 7% of the cost of AGILE PROVIDER involving the same training audience. While this comparison was made in a training environment and certainly was not an exhaustive study, it is illuminating. In order to investigate issues from this experiment in a field exercise, important components of a JTF and an associated OPFOR would need to be fielded. Even then, fielding of new technologies would be exorbitant in cost or impossible to field because they were still in development. On balance, we expect that a field exercise would be more suitable than a virtual experiment in examining issues involving physical and mental stress.

[Ackoff] points out that research is directed toward the solution of problems of two major classes: *evaluative* (also called *summative evaluation* by the instructional community) and *developmental* (also called *formative evaluation*). Summative evaluation determines how good a system is after it has been developed, but not particularly useful in producing information about how to make a system in development more useful. Formative evaluation provides information on what needs fixing, amplification, or replacement. The DSB virtual simulation involved both types of evaluation but clearly was more focused on the second type of problem.

SCENARIO DESIGN

The objective of the virtual simulation project was to demonstrate some aspect of concept exploration that could only be analyzed through virtual simulation, i.e. could not be better analyzed through constructive or live simulation. With this end in mind, a scenario

was designed which was consistent with combat scenarios under consideration by the DSB. This scenario, illustrated in Figure 1, postulated early entry into some littoral area of the world. Small teams would be inserted by helicopters from a marine based platform, supported by precision indirect fire from an arsenal ship or other remote locations including Navy based air, attack helicopters, or MLRS across the international border. The mission of the team was to interdict the movement of enemy forces through a designated terrain area to support sealing off an objective area being secured by other forces (e.g. an airfield). It was assumed for the purposes of this analysis that local security of the team would be provided by indigenous forces. Survivability of the forces, although an important issue to the new concepts, was a secondary element for this analysis. The team was provided a vehicle to move on the battlefield although some excursions examined dismounted operations. The team had no organic capability to engage targets with direct fire. The only attack capability available was indirect fire. The team was provided communications with a common data base that provided geo-location information on a digital terrain backdrop (map of the future (MOF)) and had a digital messaging system (GRUNT) for reporting information and requesting fires. Various sensor arrays were used during the excursions that included Melios (binoculars integrated with a laser range finder), COVER (a locally tethered sensor that hovered about 200 feet above the team's position like a battlefield periscope for looking over hills), and access to sensor data that would be controlled either by the Joint Task Force Commander or higher authorities. Some of the general issues under investigation included "Why do we need infan-

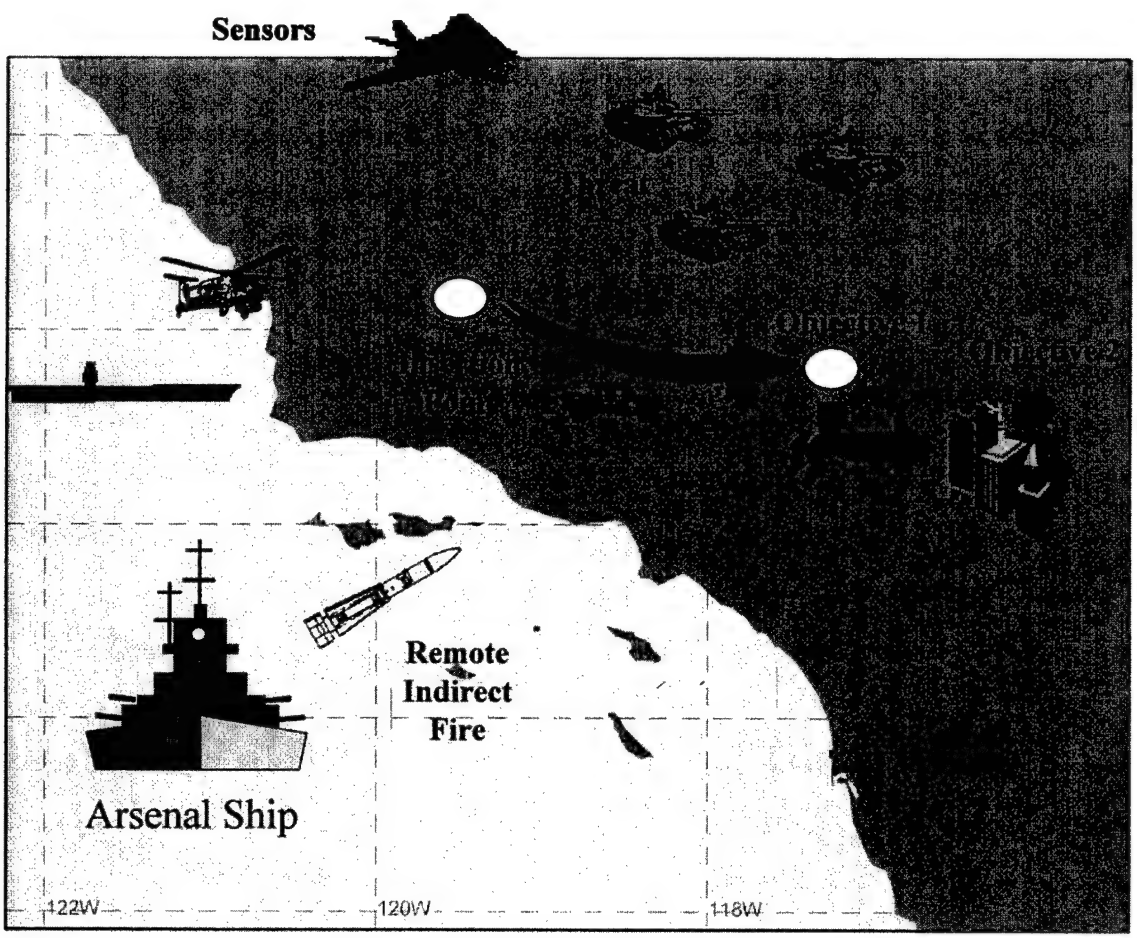


Figure 1. The Basic Elements of the Scenario Analyzed.

trymen on the ground at all?" "Given this need—what will empowerment of the infantryman do for the operation?—Will it indeed make the operation more effective or will the soldier on the ground be overpowered with information management demands?" The weapons and their characteristics postulated for this analysis are shown in Table 1. Weapons were selected to represent what would be reasonably available for the early entry scenario being designed. LTG Paul Van Riper, USMC cited to the DSB a need to reduce the time interval between call for fire and weapons impact to less than 2–5 minutes as an objective for small team survivability. A loitering missile which was called Super T-Hawk was postulated to satisfy this need.

Ordnance for the Arsenal Ship was postulated as the Navy Tactical Missile System (NTACMS) having roughly the same characteristics as the ATACMS. It is believed that the unclassified performance characteristics shown on the table for all of the systems are achievable realistically within the current state of technology.

The sensor suite used within the designed scenario and the characteristics of each sensor are shown in Table 2. In order to achieve the level of situational awareness required by the concepts being considered by the DSB, a set of notional sensors, as shown in this table with their characteristics, were postulated. As with the notional weapons, the notional sensors were given capabilities that could reasonably be expected with current or emerging technology. Further, it was postulated that a common database such as tactical internet would be available for accessing sensor data from theater or national sensors.

SIMULATION DESIGN

The physical layout of the simulation facility is shown in Figure 2. All of the components (exercise control, observers, and simulation synthetic battlespace portals) were in one large room, while exercise control stations were separated physically from portals and observers. The term "portal" was used by the DSB to mean the interface between an individual combatant (IC) and the synthetic environment. This usage may cause some confusion with the virtual simulation community, to be clarified below.

There were three portals. Portal 1 was a three walled "synthetic environment cave" around a treadmill that allowed a walking or crawling soldier to interact directly with the synthetic battlespace. Some use the term "im-

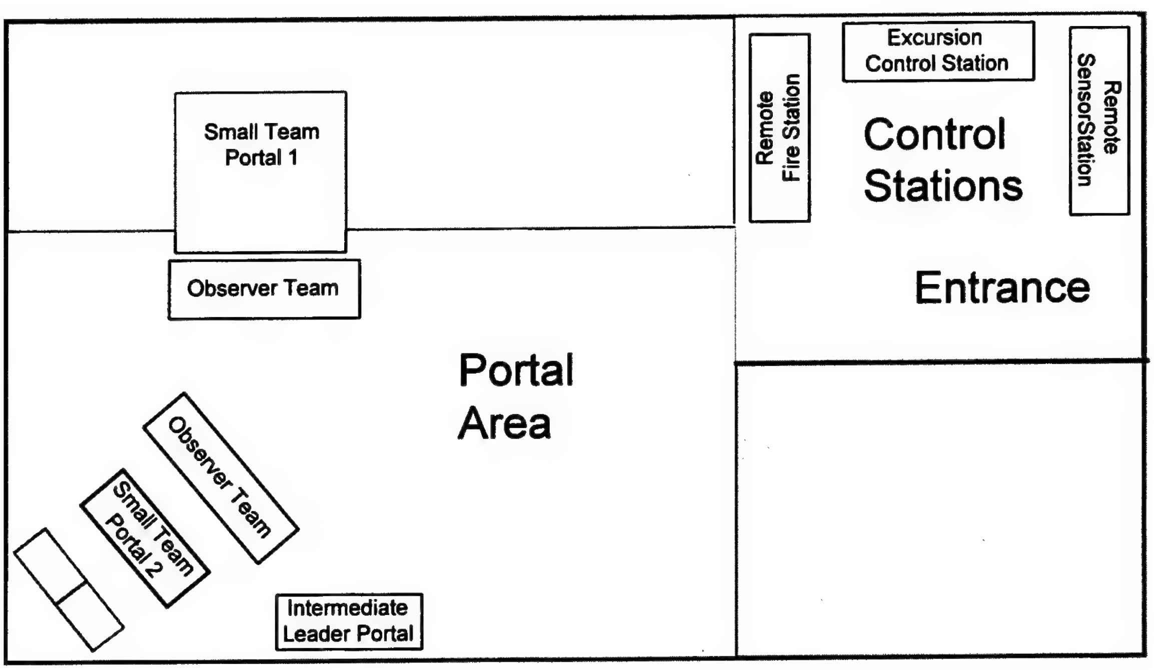


Figure 2. Simulation Facility Layout.

Table 1. Weapons Postulated for the Simulation

Characteristic		Weapons Types						
	Units	NTACM	Super T-Hawk	TACAIR F-16	How 155mm	MLRS	ATK AH64	Naval Gun
Rounds per volley	Rds	na	na	na	8	8	na	4
Aircraft per flight	A/C	na	na	2	na	na	4	na
Speed	kph	1500	500	2000	1000	1000	180	1000
Maximum Range	km	150	500	1000	30	30	500	30
Launch interval	min	2	30	0	1	1	0	1
On station time	min	na	60	20	na	na	45	na
Number of return passes	#	0	0	3	na	na	4	na
Interval between passes	min	na	na	5	na	na	2	na
Communications Intervals								
FDC to launcher	min	10	5	5	2	2	5	8
Launcher to launch	min	3	0	0	2	2	0	2
Point Target Warhead		MP	MP	MP	C'head	MP	Hellfire	DPICM
Implemented in ModSAF by	bomb	bomb	bomb	155 imp.	MLRS	Hellfire	bomb	
Laser designated Pk for tracks	Pk	0.2	0.2	0.8	0.5	0.7	0.8	0.5
Laser designated Pk for wheels	Pk	0.4	0.4	0.9	0.2	0.7	1	0.5
Laser designated Pk for troops	Pk	0.4	0.4	na	na	na	na	na
Area Target Warhead		MP	MP	MP	DPICM	MP	Hydra 70	HE
Implemented in ModSAF by		bomb	bomb	bomb	155 prox	MLRS	bomb	bomb
Footprint against tracks	m-x-m	400×400	200×200	200×200	200×200	200×200	100×100	400×400
Pk against tracks in footprint	Pk	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Footprint against wheels	m-x-m	400×400	200×200	200×200	200×200	200×200	100×100	400×400
Pk against wheels in footprint	Pk	0.4	0.4	0.3	0.2	0.2	0.4	0.2
Footprint against troops	m-x-m	400×400	200×200	200×200	200×200	200×200	100×100	400×400
Pk against troops in footprint	Pk	0.5	0.5	0.6	0.4	0.4	0.8	0.4
FASCAM								
Mines installed by ModSAF								
Footprint		400×400	na	400×400	100×100	100×100	na	na
Density (mines per footprint*)	m-x-m	400	na	500	6.5	100	na	na
Target Location Update								
Update window (before impact)	sec	120–60	120–60	300–240	na	na	60–30	na
Correction envelope	km	3	na	10	na	na	2	na
Laser designate (impact—X)	sec	na	7	7	7	7	na	na
Unattended Ground Sensor								
Num. per sortie	#	0	0	0	0	0	4	0

Launch interval of "0" indicates continuous availability. HE = High Explosive. C'head = Copperhead. Pk = probability of kill given an attack/per pass or vehicle. FASCAM = Field Artillery Scatterable Mines. DPICM = Dual Purpose Improved Conventional Munitions. MP = Multipurpose.

Table 2. Sensor Suite

Sensor	Type	Range	Coverage	Target	Data	IFF	Platform	Downlink
Existing Sensors (Operational & Developmental)								
REMBASS	Magnetic	3/25 m	Continuous	MTI	digital	no	manpack	Monitor Set
REMBASS	Acoustic	50/350 m	Continuous	MTI	digital	no	manpack	Monitor Set
REMBASS	IR Passive	3/50 m	Continuous		digital	no	manpack	Monitor Set
JSTARS	SAR	240 km	11 hrs	MTI/FTI	imagery	no	E-8A	GSM*
Predator	Radar	500 nm	24 hrs	MTI	digital	no	UAV	GSM*
Predator	E-O/IR	500 nm	24 hrs	MTI/FTI	dig./video	limited	UAV	GSM*
Tier II +	Radar/E-O/IR	3000 nm	24 hrs	MTI/FTI	multi media	limited	UAV	GSM*
Tier III −	SAR or E-O	500 nm	8 hrs	MTI/FTI	multi media	limited	UAV	GSM*
Notional Sensors								
TF UAV	FLIR	100 km	Continuous	MTI/FTI	digital	limited	UAV	MOF
	SAR				digital	limited		
	LLTV				video	limited		
REMBASS	Magnetic	400×400m	Continuous	MTI/FTI			UGS	MOF
II	Acoustic							
	IR							
Micro	LLTV	10 km	4 hrs	MTI/FTI	video	some	UAV	MOF
UAV	FLIR				digital	some		
COVER	Radar		Continuous	MTI/FTI	digital		Tethered	GSM
	LLTV				video		Hovercraft	
	FLIR				digital			

REMBASS = Remotely Monitored Battlefield Sensor. LLTV = Low level televideo. EO = Electro-optical. MTI = Moving Target Indicator. FTI = Fixed Target Indicator. UAV = Unmanned aerial vehicle. GSM = Ground Station module. SAR = Synthetic aperture radar. FLIR = forward looking infrared. IR = Infrared.
* Initially will be High Altitude Endurance (HAE) common ground segment for both Tier II and III.

mersion" to described this situation where an IC is surrounded by a synthetically generated environment. Portal 2, illustrated in Figure 3, was the driving portal, where the IC interacted with "windows" into the environment, but did not have a complete presence within the environment. This is the situation which the community uses the term "portal" in contrast to "immersion." Initially, this portal was manned with one driver and one forward observer who observed the battlefield and initiated calls for fire. Workload analysis revealed that the task load was too great for two people, so a third one was added to share in the tasks. Specifically, it took too long for the forward observer both to observe the battlefield and process calls for fire. The illustration shows what equipment interfaced with the synthetic battlespace. These included controls for a wheeled vehicle such as the High Mobility Multi-purpose Wheeled Vehicle (HMMHV), a foot pedal for dismounted operations, a MOF that provided a surrogate for future digital maps (1:50,000, scaleable to 1:100,000 and 1:250,000), and a digital message pad for electronic message forms. The digital MOF showed the location of all other known friendly and enemy forces, enabling the evaluation of situational awareness. Also provided were a radio for communications with higher headquarters and a surrogate sensor interface for locally controlled sensors such as Melios (laser range finder integrated with binoculars). Portal 3 was the intermediate leader portal that included a desk top monitor of the synthetic battlespace integrated to a MOF display. It showed team and enemy locations and permitted communications via electronic messaging. A detailed view of how the IC interfaced with the virtual battlefield is illustrated in Figure 4.

Exercise control was facilitated through three control stations, one of which is illustrated in Figure 5. The Remote Fire Station included the interfaces shown. A spreadsheet based fire control emulator was used to electronically track data on weapons used for engagement. Each fire event was recorded, in-

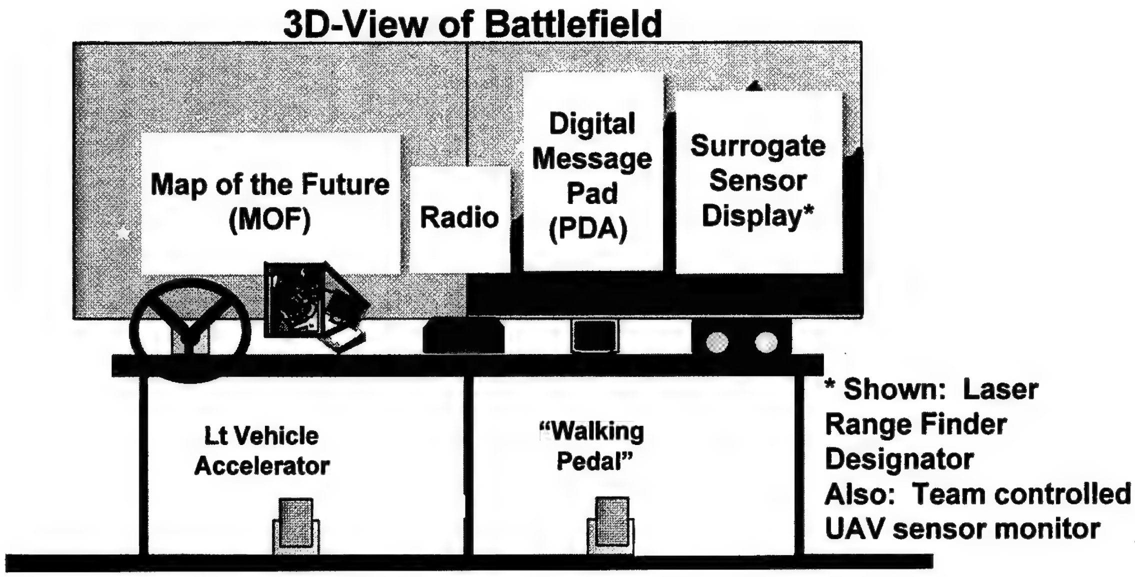
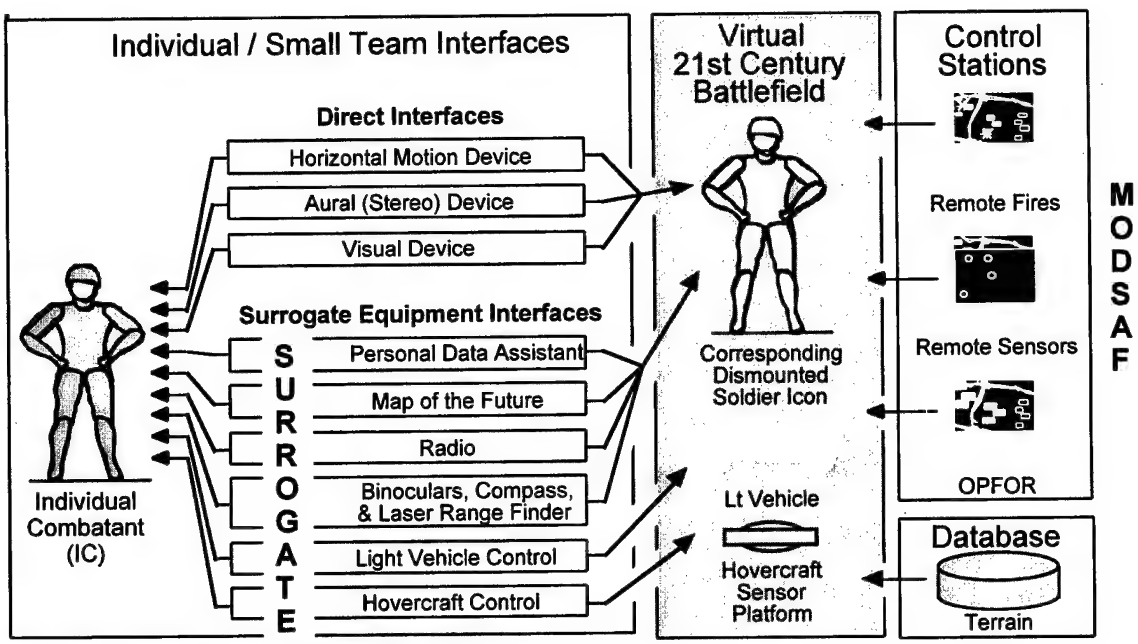


Figure 3. Vehicular Mounted Portal.



Source: James L. Madden (IDA)

Figure 4. Interfacing the Soldier with the Virtual Battlefield.

cluding the weapon identification, the remaining inventory, and the time line for the engagement. The "entity-based" ModSAF was used as the simulation engine for the exercise. The ModSAF bomb button was used to execute indirect fire missions. A MOF or GRUNT was used to receive calls for fire. (Both had this capability). The MOF was used to keep track of the location of friendly and enemy forces on the battlefield. The Remote Fire Station was

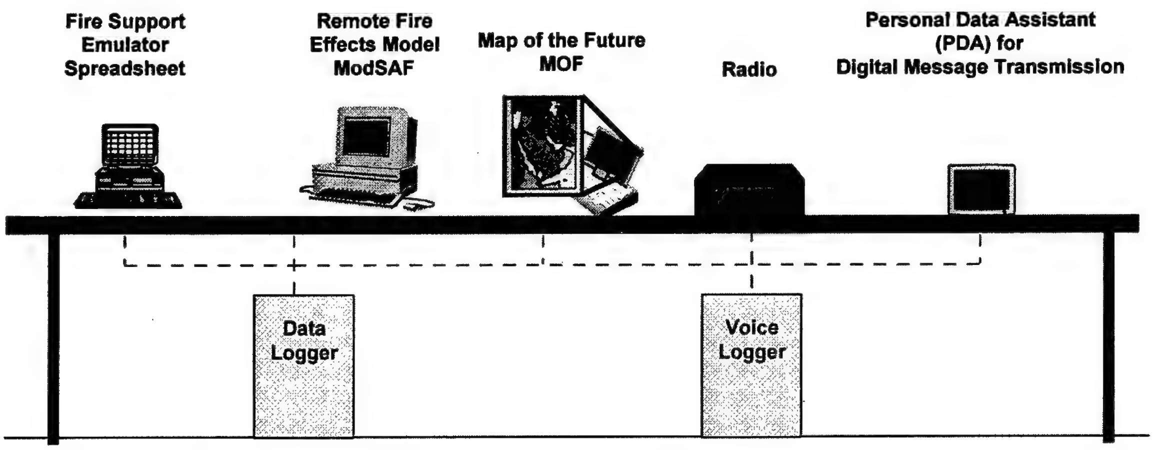


Figure 5. Remote Fire Station.

manned by two Marine Corps Captains from the USMC Artillery School and another individual managed the fire control emulator.

The other two control stations were configured similarly, without a fire control emulator. The Remote Sensor Station operator used a ModSAF terminal to replicate and control sensor activity within the simulation. Required sensor capabilities that exceeded the current inventory of ModSAF sensor models were simulated off-line and the results of their returns were manually entered into the common database accessed by the MOF. A MOF terminal also was located at the Remote Sensor Station for monitoring friendly and enemy locations.

The Exercise Director used a ModSAF terminal at his station to monitor enemy and friendly locations against the desired scenario for each excursion. The Exercise Director also served as the Commander of Higher Headquarters in receiving and responding to requests from the small teams.

The illustration in Figure 6 shows the organizational relationship between individual combatant (IC), observer, controller personnel, and their respective stations—physically shown in Figure 2.

EXCURSIONS

After two months of systems design and engineering, the simulation exercise was executed over a period of two weeks in July 1996. Marine Corps lieutenants acted as ICs in this simulation for one of these weeks, and Army captains manned the simulation as ICs in the other week. Monday of each of the two weeks was devoted to training the ICs on simulation use and postulating new doctrine and tactics. Friday of these weeks was dedicated to after action review (AAR). Two AAR sessions were held daily. One included exercise controllers and ICs. The other included only controllers. Two excursions were run on the other three days; one in the morning and another in the afternoon. A detailed schedule of configuration variables by excursion is shown at Table 3. An equipment outage precluded one scheduled excursion. The table is self-explanatory, however, we can highlight some of the issues that drove variable change.

Two terrain types were considered—open and mixed. Urban terrain was also considered and demonstrated, but resource constraints limited activities in the urban setting. Another constraining factor was the additional equipment that would have been required for urban operations. The mixed terrain provided more adequate and interesting situations than open terrain for small teams because of the greater complexity that it presented for information management. Sensor and communications capabilities were varied. On one excursion, ground truth information was provided to the small team to investigate the upper limit of information access. These variables impacted situational awareness greatly.

The mobility and missions of enemy forces were varied somewhat but not enough to make

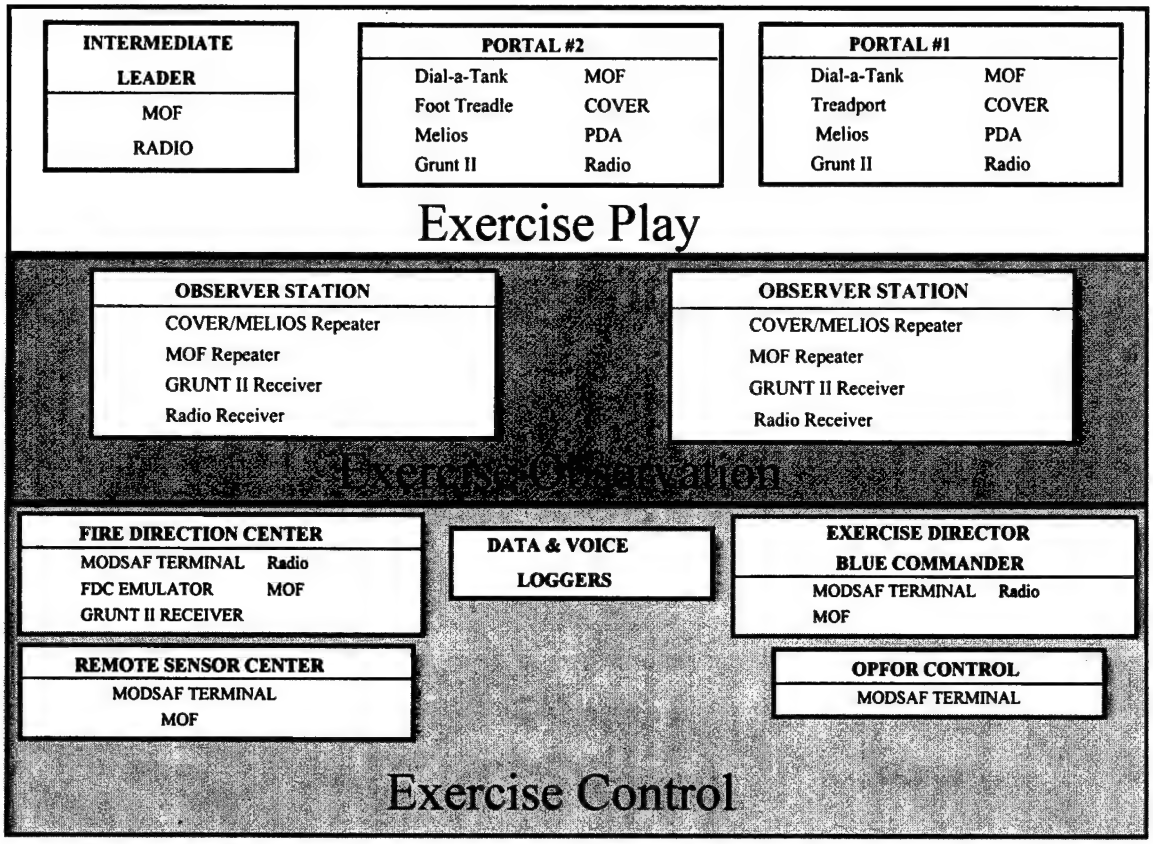


Figure 6. The Functional Design of the Exercise.

significant observations about the use of small teams versus differing enemy capabilities.

A weapons array was used that varied responsiveness, accuracy, area of impact, lethality, and control.

DATA COLLECTION AND ANALYSIS

An evaluation plan was developed around three essential elements of analysis (EEA).

1. The utility of sensors and personal data assistants (GRUNT and MOF) in enhancing small team's situational awareness.
2. The utility of remote fires in increasing the combat effectiveness of small teams.
3. The suitability of virtual simulation as a concept exploration tool.

These EEA were used for defining measures of effectiveness and performance for analysis.

Sensors and Personal Data Assistants

The utility of sensors was measured through two sets of data. The first set involved the amount of data made available to the small teams because of the availability of increasing sensing capability. These data related to impacts (workload and performance) caused by increasing amounts of information. The second set involved the requirement to manage new pieces of equipment (sensors, MOF, and PDAs). These data related to their usability and their impact on roles, responsibilities, procedures.

Remote Fires

The utility of fires was measured by small team effectiveness. Measurements included numbers of enemy killed and time to kill. The numbers killed measured general system effective-

Table 3. Simulation Excursions

Excursion	1	2	3	4	5	6	7	8	9	10	11
Environment	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural	Rural
Terrain	M	M	M	M	M	O	O	M	M	M	M
Portal I (Treadport)											
MOF	X	X	X	X	X	X	X	X	X	X	X
GRUNT	X	X		X	X	X	X	X	X	X	X
Melios	X	X		X	X	X	X				
Magnification	1–3	1–3				1–6	1–6				
COVER						X		X	X	X	X
Magnification						1–6		1–6	1–6	1–6	1–6
Elevation Rate						50 m/s	50 m/s	50 m/s	50 m/s	100 m/s	100 m/s
Mobility	D	D	D	D	D	V	D	V	V	V	V
Portal 2 (Driving Portal)											
MOF	X	X	X	X	X	X	X	X	X	X	X
GRUNT	X	X	X	X	X	X	X	X			
Melios							X				
Magnification							1–6				
COVER	X	X	X	X	X	X		X	X	X	X
Magnification	1–3	1–3	1–3	1–6	1–6	1–6		1–6	1–6	1–6	1–6
Elevation Rate	50 m/s	50 m/s	50 m/s	50 m/s	50 m/s	50 m/s		50 m/s	50 m/s	100 m/s	100 m/s
Mobility	V	V	V	V	V	V	D	V	D	V	V
Team Leader Portal			None	None	None						
MOF	X	X				X	X	X	X	X	X
Mobility	V	V				V	D	V	D	V	V
UGS (Hand Emplaced)	2	2	2	2	2	2	2	4	4	4	4
Remote Sensors											
Task Force UAV	X	X	X	X	X	X	X	X	X	X	
JSTARS	X	X	X	X	X	X	X		X	X	
Tier II/III	X	X	X	X	X	X	X			X	
Predator	X	X	X	X	X	X	X		X	X	
Ground Truth											X
Weapons											
NTACMS	X		X	X	X			X	X	X	X
Super T-Hawk	X		X	X	X			X	X	X	X
TAC AIR	X	X	X	X	X	X	X	X	X	X	X
Howitzer	X										
MLRS	X	X	X	X	X	X	X	X	X	X	X
ATK HELO	X	X				X	X				
Naval Gunfire			X			X	X				
Enemy Forces											
Mission	I	I	I	I	I	R		R			
Vehicle Speed (kph)	15	15	15	15	15	15	15	15	15	29	29
Tank Probes	9	2	2	4	4	6	6	4	4	4	5
BMP Probes	11	3	3	5	5	6	6	4	4	5	6
Truck Probes	2	1	1	2	2						
Dismt'd Probes	19	4	4	8	8	4	4	5	5	8	11

I = Infiltration. MOF = Map of the Future. GRUNT = Electronic message pad. D = Dismounted. UGS = Unattended Ground Sensor. Melios = Binoculars integrated with rangefinder. V = Vehicle. NTACMS = Arsenal Ship Tactical Msl. COVER = Sensor tethered to individual combatant. R = Reconnaissance. M = Mixed Terrain. O = Open Terrain. Super T-Hawk = Loitering Tomahawk.

ness. Time to kill measured system efficiency particularly with respect to team survivability.

Suitability of the Virtual Simulation

The data required to determine suitability consisted of that data necessary to make judgments about the benefits of virtual simulation compared with aggregated constructive or live simulation for modeling the DSB concepts.

As the experiment was designed, constructed, tested, and executed four natural areas for making such judgment emerged.

1. Concept exploration—What capabilities does virtual simulation uniquely provide?

2. Human performance—What human performance does virtual simulation measure?
3. Process Analysis—What insight does virtual simulation provide about battlefield processes that could be automated?
4. System Specification—How can virtual simulation be used best to transform requirements into system design?

Data required to answer the concept exploration EEA and these questions on suitability were collected in the categories shown in Table 4 using the methods and analyzing the functions shown. The Army Research Institute (ARI) developed the data collection and analysis plan for human behavior. ARI also participated in the exercise as expert observers in human behavior. This plan was based on data requirements for analyzing the interfaces between humans and equipment such as the MOF, workload, and human performance ARI also helped assess doctrinal, tactical, and procedural functions.

[Salter, Knerr, et al.] discuss in detail the ARI participation in this experiment. The ARI report includes its data collection plan including measures and their use in responding to the EEA.

One important human performance issue that emerged was the interface between the ICs and their equipment. In illustration, it was found that a critical requirement exists to more efficiently enter and extract information from automated devices such as voice recognition or touch screens in order to make these devices credibly functional. Since the software engineer who had originally designed some of the equipment interfaces to the IC was available during the experiment, we were able to react immediately to recommended interface improvements from the IC, effectively improving interfaces in near real time.

The entity-based simulation approach improved control of data, leveraging the data logging capabilities of ModSAF. Data logging allows the recall of any event (platforms, activity, time, location) recorded by the simulation. Other automatic data collection was performed by recording data managed by other equip-

Table 4. Data Collection

Category & EEA	Collection Methods	Functions
Behavior EEA-CE1, CE2, S1, S2, S3, S4 (Notes)	Direct Observation Questionnaire Interviews	Human • Interface • Workload • Performance
Doctrine EEA-1, S1	Observation Questionnaire Interviews	Roles & Responsibilities Organization Operations
Equipment EEA-1 & 2	The Methods above plus Automatic data collection	Data presentation & use Sensor performance Database management
Procedures EEA 1 & 2, S1	The Methods above plus Voice log	Comm procedures Managing—Targets & Tasks Battle Damage Assessment
Tactics EEA 1 & 2	All the Methods above	FASCAM Fires Mobility Sectors Situational Awareness
Training EEA 1 & 2, S2	All the Methods above	Target acquisition, tracking, & engagement Communications Managing sensors Calls for fire Situational Awareness

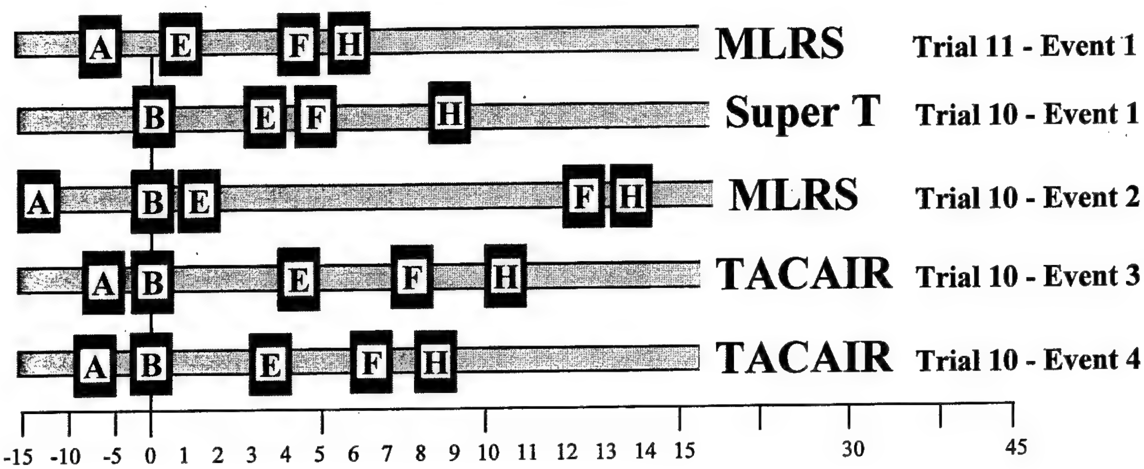
Notes: CE = Concept Exploration EEA. S = Virtual Simulation Suitability EEA.

ment used in the exercise. For instance, the fire control emulator maintained a comprehensive record of each fire engagement including the weapons used and their timeline.

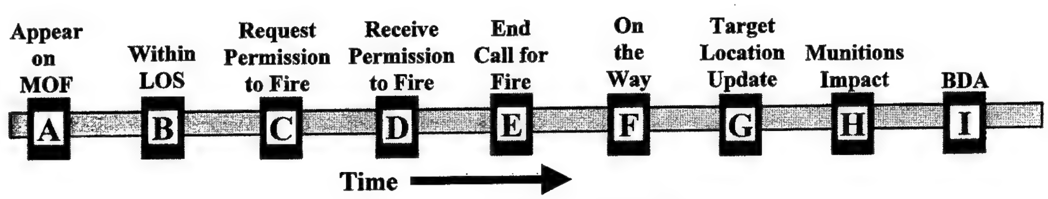
Remote Fires

In retrospect, the indirect fire support timelines probably were the most globally useful data set collected of any concept investigated. (See the snapshot of data in Figure 7 below).

Timeline compression was critical to the survivability of small teams under the scenarios postulated and to effective Joint Task Force (JTF) engagement of targets. Elaborating on the survivability issue, indirect fires were the only means of protection for small teams when they became detected by an armored threat. The need to reduce the "time-of-flight" to 2–5 minutes became an objective for small team survivability. However, none of the postulated indirect systems were able to deliver ordnance within 5 minutes of target detection. It appears that this problem might be overcome by increasing the number of a loitering missiles, thereby reducing the probabilistic range of the missile and therefore "time-of-flight." Improvement of the inflight update of missiles already on the way might also be a solution to the "time-of-flight" challenge. It would help in the engagement of targets that had moved since the call for fire was initiated and would allow ICs



Note: Missing markers indicate that the event was not observed.



- **Appear on the Map of the Future (MOF) = Target Cued by Remote Sensor**
- **Within Line of Sight (LOS) = First instance of LOS between target and observer**
- **Request permission to fire = Team Leader cannot determine if a target is within rules of engagement and request approval from higher headquarters.**
- **Receive permission to fire = Higher headquarters approves request.**
- **End of Call for Fire (CFF) = Last key stroke or voice command of the CFF.**
- **On the way = FDC acknowledgement, with impact time and munitions type.**
- **Target loaction update = Team reports updated location of target prior to missile impact. (Required for NTACMS and TAC AIR only.)**
- **Munitions impact = munitions land on target**
- **Battle Damage Assessment (BDA) = Team reports target damage.**

Figure 7. Indirect Fire Timelines.

to engage new targets that had become a greater threat to the ICs' survivability after the initial call for fire.

The snapshot data shown in Figure 7 reveals another important point. The team was unable to render effective battle damage assessment (BDA) on most enemy targets attacked. Targets were usually engaged out of the team's field of view, i.e. by the time of weapon's impact, they had moved out of the field of view.

CONCEPT EVALUATION RESULTS

In general, it was found that there was a limit to the amount of information that an individual could manage. Options to this situation required reducing areas of responsibility, relying on greater teamwork, and reapportioning tasks between the teams and the Joint Task Force. It was observed that the design of equipment used in the experiment was optimized for individual, not team use. For example, report formats in equipment menus required duplication of data entry by different individuals in the chain of people requesting fire. Also, some of the equipment designed for situational awareness (e.g. personal data assistant map viewers) did not display a sufficiently large field of view to optimize their situational awareness. While it was earlier envisioned that dismounted teams could be effective in some missions, it was found that a team needed a vehicle in all of the situations exercised to be effective. In the scenarios postulated, the battlefield operational tempo was too great for dismounted teams to keep up with the pace of enemy movement and survive.

Four specific areas for results included sensor management, weapons management, data management, and data presentation. They were organized in these broad categories to be consistent with the other analyses being conducted for the DSB.

- **Sensor Management**—Key team functions should be to detect, classify, and identify enemy forces not observable by other sensor systems and to determine enemy intent. Even where enemy forces are observable by other sensor systems, human intervention may be required to manage sensor position for observing critical aspects of targets. Cognitive capabilities of humans, "locally at the scene" can be indispensable in sensor management.
- **Weapons Management**—Teams had difficulty managing more than two targets at the same time. Survivability of the small teams require the tagging, tracking, and engaging of targets within 2–5 minutes of detection. Finally, returning to previous target for update may cause the loss of other targeting opportunities. (A corollary is that small teams should not be managing fires, rather should limit their activities to locally managing sensors for the tagging of targets and to selected BDA tasks.)
- **Data Management**—Technology should enhance C2 by providing teams the right information when needed. The use of common data bases that can be accessed by multiple teams or individual proved quite efficient for information exchange.
- **Data Presentation**—Digital, scaleable maps of appropriate size that can perform distributed automated battle management and terrain analysis are required for control of large areas. Conversely, it was found that digital maps having reduced coverage were of limited use to small team. It was important for the small team to be aware of the situation as seen a couple of levels above, not merely the weapons range of the small team.

FINDINGS ABOUT THE USE OF VIRTUAL SIMULATION FOR CONCEPT EVALUATION

Findings on the utility of virtual simulation are organized into four categories—concept exploration, human performance, process analysis, and system specification. All of the findings are presented in terms of benefits provided by virtual and entity-based simulations in comparison with aggregated constructive simulations.

- **Concept Exploration**—Virtual simulation provides an effective environment for creating and experimenting with new doctrine, tactics, and techniques. New capabilities include the synthetic battlespace, providing variability of environments; and entity-based simulation, providing a mechanism for creating future combat systems, interoperability between models, and modularity in simulation and analysis design.
- **Human Performance**—Virtual simulation enables the investigation of individual workload (e.g. task and information management,

skill definition; including teamwork and cognitive impacts), roles (e.g. sensor, shooter, fighter tradeoff), and equipment interface.

- **Process Analysis**—Virtual simulation is an appropriate technique for assessing new battlefield processes such as sensor and weapons management. Sound process analysis assures that we apply new technology to new processes when appropriate, rather than automate obsolete processes.
- **System Specification**—Development of the virtual simulation design requires understanding of included processes such as fire support to the detail necessary to accurately specifying requirements for system design—the crucial detail being the human as an element of the combat system.

If these findings are comprehensive in some way, then the utility of virtual simulation for concept exploration could be limited to the investigation of information management issues. While this exercise did not fully investigate these limits, it seems likely that the examination of physics based phenomena may better be pursued using other techniques such as constructive simulation.

SUMMARY

It's not clear from this experiment that we fully answered general issues such as "Why we must have infantrymen on the ground in the future?", although we were able to provide insight and surface evidence about information processing capabilities yielded from individuals' cognitive abilities that cannot realistically be expected from technology over the next twenty years. In order to resolve better such issues further experimentation is required.

On the other hand, the experiment did demonstrate great potential for using virtual simulation in concept exploration especially for assessing human interfaces to complex information systems. One major benefit in virtual simulation over aggregated constructive and live simulation included the ability to quickly and economically create variation in a future environment (threats, visibility, geography, technologies, organization, doctrine, and tactics). Another benefit was in enabling investigation of what arguably is the most important and complex part of any battlefield system—the human element. While live simulation also can be used for this purpose, live simulation generally is more costly and it cannot provide the variability required for future concepts nor can it integrate the variables effectively in the controlled way enabled by virtual simulation.

There also appears to be a special benefit in using advanced distributed simulation in simulation for experimental design. Entity-based simulation facilitates interoperability of models, supports comprehensive data collection and analysis, and enables the articulation of futuristic systems that can be designed at an appropriate level of fidelity.

This experiment did not fully test the limitations of virtual simulation for concept exploration. While this experiment demonstrated value for exploring complexity, the author believes that analysis of simpler problems such as those involving the physics of weapons systems might best be pursued with closed form analytic models which are repeatable, deterministic, and can be supported by stable theory.

Future work should examine the relationships between virtual, live, and constructive simulation for analysis. More work is suggested for the design of experiments that support usability engineering, particularly using virtual simulation. The development of tools to improve usability engineering also seems to be a worthwhile objective.

REFERENCES

Department of the Army, Pamphlet 70-3, *Army Acquisition Procedures*, Wash. D.C. 28 Feb. 1995, p. 32.

Ackoff, R. L., *Scientific Method*, John Wiley & Sons, N.Y. 1962.

Battilega, J. A. and Grange, J. K., *The Military Applications of Modeling*, Air Force Institute of Technology Press, Wright Patterson AFB, Ohio, 1984.

Bracken, J., Kress, M., and Rosenthal, R., (eds.), *Warfare Modeling*, MORS, John Wiley & Sons, Danvers, MA, 1995.

Coe, G. Q., Madden, J. L., Mengel, L. L., and Wright, R. K., *Virtual Simulation Support to the 1996 Defense Science Board Summer Study "Tactics and Technology for 21st Century Military Superiority,"* Institute for Defense Analyses Doc D-1988, Alexandria, VA., Feb 1997.

Davis, Paul K. and Blumenthal, Donald, *The Base of Sand Problem: A White Paper on the State of Military Combat Modeling*, RAND, Santa Monica, CA, 1991.

Dreyfus, Hubert L. *What Computer's Can't Do*, Harper Colophon Books, 1979.

Dreyfus, Hubert L. *What Computer's Still Can't Do*, The MIT Press, 1992.

Garrett, Randy, "A New Simulation Paradigm: Advanced Distributed Simulation, PHALANX, Sept 1995.

Landauer, Thomas K., *The Trouble With Computers*, The MIT Press, Cambridge, MA, 1995.

Nielsen, Jakob, *Usability Engineering*, Academic Press, Boston, MA., 1993.

Przemieniecki, J. S., *Introduction to Mathematical Methods in Defense Analyses*, AIAA, Wash. D.C. 1990.

Salter, Margaret S., Knerr, Bruce W., Lampton, Donald R., Fober, Gene W., and Dressel J. Douglas, *Small Team Portal Into the 21st Century STP21*, U.S. Army Research Institute for the Behavioral and Social Sciences, Office of the Deputy Chief of Staff for Personnel, U.S. Army, December 1996.

Schwartz, R. E. and Stahl, M. M., *Innovative Analytic Techniques for Distributed Interactive Simulation (DIS)*, Institute for Defense Analyses Doc. D-1902, Alexandria, VA., Sep 1996.

Schuetze, Dianne, et al. "DIS User Requirements for Advanced Concept Requirements Analysis", Presentation Paper, HQ., TRADOC, 1966.

Sowa, J. F., Conceptual Structures, Addison-Wesley, Yorkstown Heights, N.Y. 1984, pp 339–365.

Sikora, Jim & Coose, Phil, "What in the World is ADS," PHALANX, June 1995.

Stuart, Roy, *Design of Virtual Environments*, McGraw-Hill, 1996.

Thomas, John, "Report on AT2D2 Experiment," AMSSA Report presented at 6th Conference on Behavior and Computer Generated Forces, 1996.

Worley, D. R., Simpson, Henry K., Moses, Franklin L., Aylward, Matt, Bailey, Michelle, *Utility of Modeling and Simulation in the Department of Defense: Initial Data Collection*, Institute for Defense Analyses Doc. D-1825, Alexandria, VA., May 1996.

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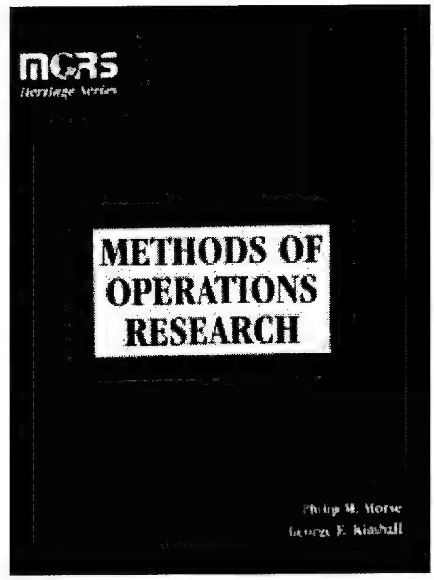

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The Cost Exchange Ratio: A New Aggregate Measure of Cost and Operational Effectiveness

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ABSTRACT

This paper introduces a new aggregate measure of cost and operational effectiveness, the Cost Exchange Ratio. Aggregate measures have been used for many years, but have been primarily concerned with operational effectiveness. We develop the basic formalism, which is amenable to any combat modeling or simulation effort analysis. Next, we present an example using Lanchester attrition theory to demonstrate the utility of the method in concepts analysis and evaluation. Finally, we establish a baseline Cost Effectiveness Ratio using Formal Aggregation Theory as a methodology aggregation.

I. INTRODUCTION

Recently, military services' downsizing has given rise both to accelerated acquisition mechanisms such as Advanced Technology Demonstrations (ATDs) and Rapid Acquisition Programs [Army S&T Master Plan, 1995] and to greater emphasis on user involvement and life cycle modeling, simulation, and analysis (MSA). Punctuated MSA efforts such as Trade-Off Analyses/Determinations and Cost and Operational Effectiveness Analyses (COEAs) have either fallen into disuse or suffered massive changes of character as the role of joint requirements intensifies.

These changes, and the increased number of technological concepts have increased the need for MSA to support decision making at all levels from the local Program Element/Project Manager through senior service leadership. The needs of these decision makers for metrics seems to enjoy a degree of commonality albeit for somewhat different reasons. At the local level, the limitations of resources and the large number of concepts dictates a need for timely and simple but accurate estimations of the concepts' military value and cost. At the senior level, the same considerations, intensified by sheer workload and evolving National military requirements dictate similar needs. To address these needs we introduce Cost Exchange Ratios as metrics of both cost and operational effectiveness amenable to any level of MSA from a simple *ad hoc* spreadsheet simulation (which we use for our example,) through formal, detailed analyses such as COEAs.

II. EFFECTIVENESS ANALYSIS OVERVIEW

Traditionally, military concepts, whether they be new weapon systems, new organizations, or new Tactics, Techniques, and Procedures, have been analyzed in their natural environment of military operations. By and large, these efforts have been conducted using simulations, in the form of either field exercises and trials, or machine based constructs: analytical; man-in-the-loop; or a combination. Occasionally, actual military operations permit incorporation of concepts (e.g., the Marines' use of "Sticky Foam" in Somalia) which are amenable to *post hoc* analysis. While these analyses consider various metrics such as force movement and mission accomplishment as well as force loss, the latter remain key factors, even for non-weapon concepts, and it is thus useful to define exchange ratios in this context.

We shall limit our further discussion to constructive simulation although the elaboration to other forms is straightforward. Traditional military simulations, be they platform or aggregate resolution, are two-sided traditionally designated as Red (usually the opponent or enemy) and Blue (usually the friendly or self). In platform level simulation (e.g. CASTFOREM), individual weapons platform types (or small organizational units—e.g., fire teams) are the common token of aggregation with the functional operation and interaction of the platforms typically adjudicated by a mixture of stochastic sampling and rules application (which may itself be stochastic). While several aggregate metrics are usually considered, three common ones are: the duration (simulated clock time) of the military operation (τ); the Killer-Victim Scoreboard (KVS); and the Rounds Fired Scoreboard (RFS).

While the duration seems obvious (but is possibly ambiguous), the other two are less so. Both of these are matrices. As we have indicated, it is common in these simulations to aggregate in terms of platform type although it is equally feasible to aggregate in terms of military organization. Let us designate that there are a total of N platform types between the two sides, $N = N_A + N_B$, where N_A and N_B are, respectively, the number of Red and Blue platform types. The KVS is then an N by N matrix whose $i, j (i, j = 1 \ldots N)$ entry is the number of the i^{th} type platforms killed during the operation by the j^{th} type platforms. In a similar manner, the RFS is also an N by

OR METHODOLOGIES: Cost Analysis; Wargaming
APPLICATION AREA: Cost Analysis; Modeling, Simulation & Gaming; Long Range/Strategic Planning

N matrix whose i, j entry is the number of rounds fired by the i^{th} type platforms at the j^{th} type platforms. In the absence of fratricide, these matrices are block off diagonal with zero diagonal elements. This being the case, we may concentrate on these non-zero off-diagonal blocks which represent the number of Red, Blue platforms killed (rounds fired) by (at) Blue, Red platforms. We may readily designate these for mathematical purposes as $\Delta A_{l,m}$ and $\Delta B_{m,l}$, $l = 1 \ldots N_A$, $m = 1 \ldots N_B$ for the reduced KVS and $\Delta a_{l,m}$ and $\Delta b_{m,l}$ for the reduced RFS. Initial (start of combat) numbers of platforms $A_l(0)$ and $B_m(0)$ are parameters. The relationship to both homogeneous and heterogeneous Lanchester attrition theory is straightforward. [Taylor, 1983], [Fowler, 1996]

III. EXCHANGE RATIOS

Exchange ratios have a long history of usage. [Schenk, 1982] Two common operational effectiveness ratios are the Loss Exchange Ratio, defined by,

$$\begin{aligned}\rho_{LE}(\tau) &\equiv \frac{\Delta B(\tau)}{\Delta A(\tau)},\\ &\equiv \frac{\sum_{m=1}^{N_B} e_m^B \sum_{l=1}^{N_A} \Delta B_{m,l}(\tau)}{\sum_{l=1}^{N_A} e_l^A \sum_{m=1}^{N_B} \Delta A_{l,m}(\tau)},\end{aligned} \tag{1}$$

and the Force (or relative) Exchange Ratio, defined by,

$$\begin{aligned}\rho_{FE}(\tau) &\equiv \frac{A(0)}{B(0)}\,\rho_{LE}(\tau) = \frac{A(0)}{B(0)}\frac{\Delta B(\tau)}{\Delta A(\tau)},\\ &\equiv \frac{\sum_{l=1}^{N_A} e_l^A A_l(0)}{\sum_{m=1}^{N_B} e_m^B B_m(0)}\,\frac{\sum_{m=1}^{N_B} e_m^B \sum_{l=1}^{N_A} \Delta B_{m,l}(\tau)}{\sum_{l=1}^{N_A} e_l^A \sum_{m=1}^{N_B} \Delta A_{l,m}(\tau)},\end{aligned} \tag{2}$$

where the top form in equations (1) and (2) is the homogeneous form and the lower is the heterogeneous form. Homogeneous and heterogeneous are used here in the Lanchester sense. The coefficients $\{e_m^B\}$, $\{e_l^A\}$ are the aggregation coefficients (or scores) for the Blue, Red sides, respectively, normed to a base platform type for each, and τ is the duration (simulated clock time) of the military operation.

The Loss Exchange Ratio is, just as its name implies, the ratio of Blue combat losses to Red combat losses. Values of this ratio less than one indicate greater Red than Blue loss and thus may indicate superior Blue combat effectiveness.

This comparison tends to be more meaningful if the two forces are initially approximately evenly matched. This situation has not been commonly perceived as relevant, first during Containment when Warsaw Pact forces enjoyed a large numeric Order of Battle superiority over NATO forces, and now under conditions of Force Projection from CONUS. This leads to consideration of the Force Exchange Ratio which is just the ratio of the fractional Blue losses to the fractional Red losses. Values of this ratio less than one indicate greater fractional Red losses than fractional Blue losses, and thus indicate superior Blue combat effectiveness.

From a mathematical standpoint, both of these ratios may be viewed as time functions which are essentially indeterminate at the start of combat and may fluctuate rapidly until both sides incur some mathematically reasonable number of losses. Utility of these ratios presupposes their stability as a measure of combat evolution. For our purposes here, we assume this stability and consider these ratios as fixed values evaluated at the end of the combat. Extension to continuous trajectories over most of the combat duration is straightforward, and while valuable, beyond the scope of this brief paper.

Both of these ratios are concerned only with the operational effectiveness of the two forces without consideration of their cost effectiveness. Cost effectiveness, both of weapons platforms in particular, and forces in general, is a matter of concern both in terms of planning and execution. This importance is demonstrated by the requirement of Cost and Operational Effectiveness Analyses at most milestone reviews during the life cycle of weapon acquisition programs and by similar analyses associated with force and operations planning used in developing campaign plans, national and regional military strategies, and budget submissions.

To our knowledge, however, the common integration of cost and operational effectiveness

is at "the bottom line." This has the advantage of maintaining independence between cost and operational analysis efforts, but it reduces the flexibility and scope of analytical efforts to "optimize" both cost and operational effectiveness. In essence, the overall "system' of cost and operational effectiveness cannot be optimized although the "subsystems' of cost effectiveness and operational effectiveness can be optimized. This may result in overall suboptimality and either exclude possible solutions from consideration or skew the decision making process.

IV. COST EXCHANGE RATIOS

In considering the costs aspects of combat, we may identify three specific areas:

(1) loss of friendly assets;
(2) expenditure of ammunition stockpile; and
(3) differential upkeep of forces;

which are additional costs incurred as a result of the combat. The first of these is the most complicated. At the tactical level, it is the economic loss incurred due to the loss of weapons platforms in combat. At the operational level, it could also include future losses incurred due to these present losses. At the strategic level, it could further include reduction of the nation's ability to prosecute war due to production or morale losses. At the grand strategic level, it could even include long term national losses resulting from territorial losses or war indemnities. The scope of our investigations have thus far been at the tactical level and we shall limit our further discussion to this level while recognizing both greater scope and further opportunity to explore that scope.

The second cost area is the economic loss incurred by engaging (killing) enemy weapons platforms. The third is the differential cost incurred by deploying the force to the combat locale and maintaining, operating, and supporting it there. Because of the highly complex nature of the reasons for field operations, the accompanying complexity of estimating these differential upkeep costs directly, and their dependence on the specifics of the deployment, we shall incorporate them in what we shall hereafter refer to as replacement cost for this description, recognizing that they could be included explicitly in a detailed study using this methodology.

If we assume that under ideal conditions, it is desirable to maintain a prescribed level of force capability, represented by numbers of weapons platforms and ammunition types, then we may use that level of force capability as the basis of definition of a metric. Particularly, if that level is to be maintained, then combat losses must be replaced after combat (ideally before another combat occurs), and the cost of replacing those losses provides a basis for a metric of the cost of operational effectiveness.

The concept of replacement cost is somewhat different from the normal accounting consideration and represents some simplification for the purpose of defining a metric. While the concept is readily understandable to anyone who has lost a car in an accident or has replaced a failed household appliance, it is not readily consistent with common defense accounting practice.

Under certain circumstances, replacement cost may actually be zero. This is the case for weapons developed and deployed for one combat (e.g., the original nuclear weapons,) or for weapons systems (ammunitions) which are at or nearing obsolescence. For the former, replacement was never intended and the cost is all sunk. For the latter, the old platform (ammunition) would have been replaced (outside combat conditions) by a new platform (ammunition).

If we neglect these two cases, then we may safely assume that under most conditions, replacement cost is nonzero, but it is not obviously incremental. In particular, we must note that while most weapons platforms (and ammunition) are produced under manufacturing conditions, there are non-production costs associated with technology research and development, product development and testing, and factory tooling and start-up costs. These costs must already have been paid if the system is fielded. In addition, there are other costs which must be considered: the life cycle cost of maintaining the system; and the cost of refactorization and production if initial production has been completed.

These are all factors which have been amply considered in various previous cost studies and analyses, so we shall assume suitable capability for developing replacement costs.

Since replacement cost is thus effectively the cost of implementing a policy of inventory replenishment, a learning curve algorithm, adjusted for the start-up and other costs mentioned above, seems appropriate. This is a traditional model incorporating production rate variables [Moses, 1995] modified to incorporate a constant for extraneous variables. The incremental unit cost model [Sherrill] for learning curves is more appropriate than the cumulative average cost [Wright, 1936] because the latter weights early instances more heavily and thus averages out period-to-period changes in average cost. [Liao, 1988] This model has the mathematical form,

$$I = aQ^bR^d + K, \tag{3}$$

where I is the unit replacement cost, Q is the cumulative quantity produced, R is the unit production rate, a is the first unit cost, b is the learning curve slope, d is the production rate slope, and K is the additional unique unit cost. The latter variable may be expected to also include logistics and maintenance costs.

This model may also be used to describe the cost of crew replacement. The question of the value of a human being is charged with emotional, social, and cultural overtones. If our consideration is limited to the tactical level, then the cost of crew replacement consists of the incremental costs of recruiting, training, and deploying the crews of the replacement systems and the funeral and survivor benefit costs for the lost crews, all of which may be described in terms of a production model such as equation (3). At the operational through grand strategic levels, additional costs are incurred which have increasing subjective nature.

The Loss Exchange Ratio, a meaningful metric of some aspects of operational effectiveness, may be used as a philosophical springboard for a metric of cost and operational effectiveness. We may recall that the Loss Exchange Ratio is the ratio of the fractional friendly loss to the fractional enemy loss. For the case where each force is comprised of only one platform type (homogeneity), this ratio may be formed easily and directly. When one or both forces consist of multiple platform types (or equivalently, organizational types,) then some form of aggregation is necessary. Regardless, the Loss Exchange Ratio is fundamentally the ratio of fractional losses at a level of equivalence. A straightforward extension to include cost may be formed by defining equivalence in terms of the replacement costs of the losses. We call this quantity the Cost Exchange Ratio.

As we have indicated, there are two replacement costs to be considered: the cost of platform replacement; and the cost of ammunition replacement. We define the quantities φ_l^A, φ_m^B to be the unit platform replacement costs for each Red, Blue platform type, and ψ_l^A, ψ_m^B to be the unit ammunition replacement costs for each Red, Blue platform type. This assumes each component has only one weapon system, but this is not a restriction except as a simplification. We further assume the unit platform replacement costs to include the cost of a basic load of ammunition, and it may include the platform's share of the ammunition stockpile. With these definitions, we may define the total force replacement costs for the two forces as

$$C_A(t) \equiv \sum_{l=1}^{N_A} \varphi_l^A A_l(t),$$

$$C_B(t) \equiv \sum_{m=1}^{N_B} \varphi_m^B B_m(t). \tag{4}$$

The costs to each force due to their combat losses are just the combination of platform loss and ammunition loss,

$$\Delta C_A(t) \simeq \sum_{l=1}^{N_A}\sum_{m=1}^{N_B} (\varphi_l^A \Delta A_{l,m}(t) + \psi_l^A \Delta a_{l,m}(t)),$$

$$\Delta C_B(t) \simeq \sum_{m=1}^{N_B}\sum_{l=1}^{N_A} (\varphi_m^B \Delta B_{m,l}(t) + \psi_m^B \Delta b_{m,l}(t)). \tag{5}$$

These are approximate since they double count the rounds fired by killed platforms. We shall accept this discrepancy as a necessary restriction since it is essentially impossible to calculate in an aggregate (e.g., Lanchester) simula-

tion. Alternately, a proportional reduction of the RFS using the ratios of surviving to total platforms of each type could be used as an approximation. The discrepancy can be eliminated by modifying a platform level simulation to produce two RFS, one for rounds fired by killed platforms and the other for rounds fired by surviving platforms. The latter RFS would then be used in equations (5). So long as the ammunition stockpiles are large, the ratio of ammunition (per round) cost to platform cost is small, and combat losses occur for all platforms, then the effects of this discrepancy should be small.

With these quantities, we may now define the Cost Exchange Ratio as,

$$\rho_{CE}(t) \equiv \frac{C_A(0)}{C_B(0)} \frac{\Delta C_B(t)}{\Delta C_A(t)}. \tag{6}$$

As with the Force Exchange Ratio, the Cost Exchange Ratio is just the (approximate) ratio of the fractional cost loss of the Blue force to the fractional cost loss of the Red force. Values of this ratio less than one indicate that the Blue force is more cost effective in the combat than the Red force.

This presumes, of course, that the economic bases of the two forces (nations) may be compared, so we would not expect this metric to be useful if the two forces represent disparate economic cultures. Further, while this metric does represent a combination of cost and operational effectiveness, and thus adds new flexibility and scope to analysis, it manifestly cannot represent a complete picture of combat. We shall address this consideration specifically below with the Normed Cost Exchange Ratio.

Several limiting behaviors of the Cost Exchange Ratio may be noted. For the homogeneous form (whether *ab initio* or by aggregation), the ratio reduces to

$$\rho_{CE}(\tau) = \frac{\overline{\varphi^A}\bar{A}(0)}{\overline{\varphi^B}\bar{B}(0)} \frac{\overline{\varphi^B}\Delta\bar{B}(\tau) + \dfrac{\overline{\psi^B}}{p_B(kill|shot)}\Delta\bar{A}(\tau)}{\overline{\varphi^A}\Delta\bar{A}(\tau) + \dfrac{\overline{\psi^A}}{p_A(kill|shot)}\Delta\bar{B}(\tau)}. \tag{7}$$

where the overbar quantities indicate aggregates. This result takes advantage of the integrated Quadratic Lanchester Attrition Differential Equation, $\Delta\bar{A}(\tau) = \alpha\int_0^\tau \bar{B}(t')dt'$, and $\alpha \sim$ *(rate of fire)*p_B*(kill|shot)*, to form $\Delta\bar{b}(\tau) \sim p_B(kill|shot)^{-1} \Delta\bar{A}(\tau)$.

With a bit of algebra and the use of equation (2), equation (7) reduces to

$$\rho_{CE} = \frac{\rho_{FE} + \dfrac{\bar{\psi}_B}{\bar{\varphi}_B p_B}\dfrac{\bar{A}(0)}{\bar{B}(0)}}{1 + \dfrac{\bar{\psi}_A}{\bar{\varphi}_A p_A}\dfrac{\bar{B}(0)}{\bar{A}(0)}\rho_{FE}}. \tag{8}$$

For modern weapon systems with high probability of kill given a shot, platform replacement costs much larger than ammunition replacement costs ($\varphi \gg \psi$), and approximately equal initial force strengths, equation (8) approaches the form,

$$\rho_{CE} \simeq \rho_{FE}, \tag{9}$$

which may have some utility as a rule of thumb or decision support flag for more detailed inspection of the underlying combat results.

The problem of comparing disparate force (national) economies may be alleviated by making use of an aggregation methodology such as Formal Aggregation Theory [Fowler, 1997]. An aggregation of this type reduces the heterogeneous situation to a homogeneous one in terms of a base platform (or unit) type. This offers an obvious basis of cost comparison which we use in the Normed Cost Exchange Ratio, defined as

$$\overline{\rho_{CE}} \equiv \frac{C_{\bar{A}}(0)}{C_A(0)} \frac{\Delta C_A(\tau)}{\Delta C_{\bar{A}}(\tau)}, \tag{10}$$

where $C_{\bar{A}}(0)$ and $\Delta C_{\bar{A}}(\tau)$ are the total force and combat loss replacement costs in terms of a base platform type aggregation. These latter represent the costs of an equivalent force comprised only of the base platform type. This ratio permits comparisons among different platform types and ammunitions on the basis of equivalent combats within a common economic framework.

V. EXAMPLE

To illustrate these ratios, we present a simple example of their use. We make use of the

Table 1. Attrition Rate Coefficients for Example

Target/ Firer	Blue 1	Blue 2	Target/ Firer	Red 1	Red 2
Red 1	0.1	0.2	Blue 1	0.15	0.25
Red 2	0.3	0.35	Blue 2	0.4	0.3

2×2 Intensive Formal Aggregation of the heterogeneous to homogeneous Lanchester problem. [Fowler, 1997] The attrition rate coefficients are given in Table 1. Rates of fire for all systems are four rounds per time unit. The force strength trajectories for this example, both individual and aggregate, are shown in Figure 1. The individual force strength trajectories are simple (numerical) integrations of the heterogeneous Lanchester attrition differential equations for the four platform types (Red 1 and 2, Blue 1 and 2) for initial force strengths of 100 and 50 for Red, and 75 and 35 for Blue. The aggregate force strength trajectories (labeled Red agg and Blue agg) are the homogeneous aggregates (equivalent Red, Blue) of these individual trajectories. The aggregation coefficients, which are derived from the attrition rate coefficients of Table 1, are: Red (1.0, 0.95); and Blue (1.0, 1.40). The Red, Blue force was aggregated using Red, Blue 1 platform as the base, as indicated by the aggregation coefficient value of 1. In this aggregation, Red 2 platforms have operational "value' 95% of Red 1 platforms while Blue 2 platforms have operational value 140% of Blue 1 platforms.

The costs of these platforms and their ammunition are given in Table 2. The Red platforms have lower cost than the Blue platforms, although the costs of the ammunition is the same for platforms labeled 1 and 2, respectively. These values roughly represent the relative market prices of Former Soviet Union and NATO ground combat platforms, and of tank ammunition and second generation antitank guided missiles.

Loss Exchange (labeled LER), Force Exchange (FER), and Cost Exchange (CER) Ratios, and Normed Cost Exchange Ratios for the Red and Blue forces (NCERA, NCERB) are shown in Figure 2. For the latter two ratios, as indicated above by the aggregation coefficients, the first system type of each force is the base system.

From Figure 2, we may see the same structure among the Loss, Force, and Cost Exchange Ratios. Clearly, Red is performing to greater effectiveness than Blue, as we may plainly see by examining Figure 1. Nonetheless, Blue is relatively more cost effective than Red as dem-

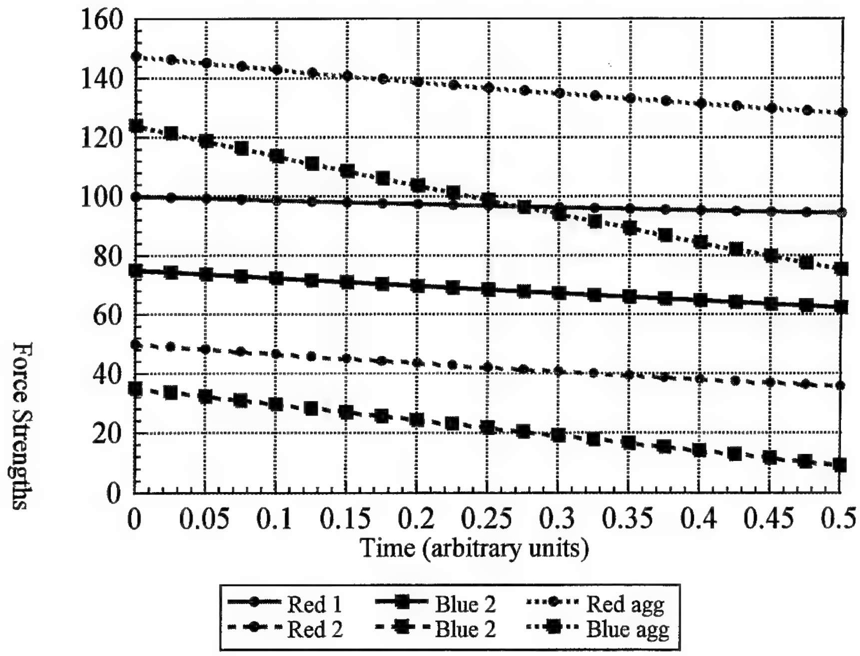

Figure 1. Force Strength Trajectories

Table 2. Costs for Example (dollars)

Type/Cost	Platform (millions)	Ammunition (thousands)
Red 1	1	1
Red 2	1	10
Blue 1	4	1
Blue 2	2	10

onstrated by the smaller magnitude of the Cost Exchange Ratio, despite the fact that it is greater than one. This apparent contradiction is a direct result of the greater Red lethality against Blue 2 and its relatively lower replacement cost.

The two Normed Cost Exchange Ratios relate costs normed to the first platform type in each case. The Red Normed Cost Exchange Ratio is greater than one, which indicates decreasing the percentage of Red 2 would be more cost effective. This result can be seen from the ammunition replacement cost in Table 2. Similarly the Blue Normed Cost Exchange Ratio is less than one indicating that an increase in the number of platforms of the second type with a decrease in the number of first type platforms would be more cost effective. This may be seen from the platform replacement cost in Table 2 and the aggregation coefficient values since a system that is half as expensive and 40% more deadly will be more cost effective.

VI. CONCLUSION

This paper presents a pair of ratios, the Cost Exchange Ratio and the Normed Cost Exchange Ratio, which are metrics that combine cost and operational effectiveness. As such they extend the scope and flexibility of analysis of weapon system acquisition, force structuring and planning, etc. These ratios follow directly from the definitions of replacement cost and Force Exchange Ratio.

This methodology appears to offer considerable promise as an analytical tool. For example, it is possible (for one side,) to effectively fix the Force Exchange Ratio and minimize cost by adjusting force composition. Alternately, it is also possible to fix cost and optimize Force Exchange, again by adjusting force composition. We must note however, that since each ratio is a point aggregation for a specific combat situation, proper consideration should be given to a spectrum of combat situations as a framework for such optimization.

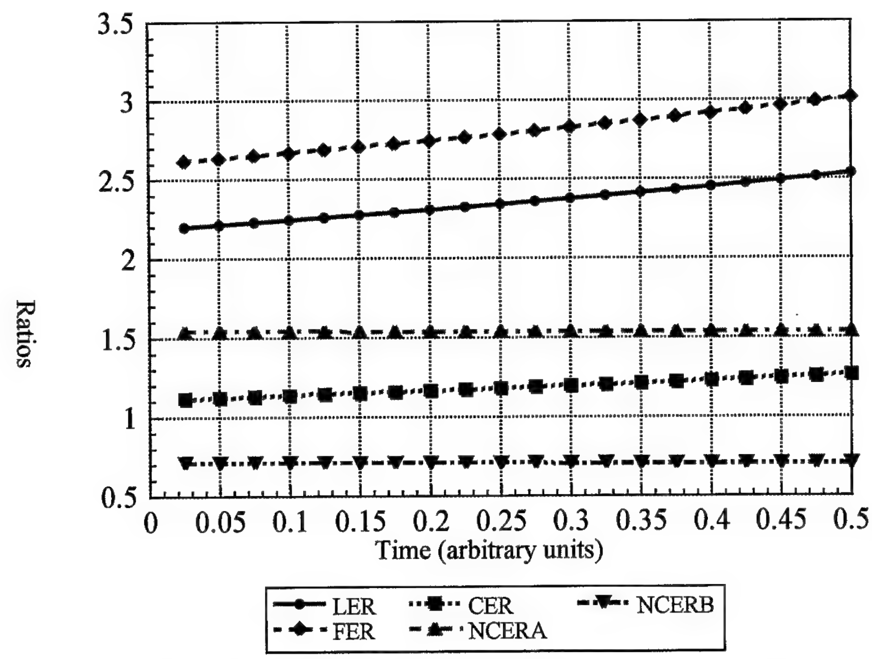

Figure 2. Loss, Force, Cost, and Normed Cost Exchange Ratios

Nonetheless, given such consideration, the Cost Exchange Ratio could be used to support both programmatic and force structure decisions. This is particularly important in a period of constrained resources and uncertain mission requirements. It provides a basis of consideration of system modernization or improvement in the context of Cost as an Independent Variable. Further, within a system of systems context, either for a single service or jointly, it provides a metric for constructing a balanced force within affordable limits.

REFERENCES

Department of the Army, **Army Science and Technology Master Plan,** Washington, DC, 1995.

Fowler, Bruce W., "De Physica Belli: An Introduction to Lanchestrian Attrition Mechanics, Part III," Defense Modeling, Simulation, and Tactical Technology Information Analysis Center, State-of-the-Art-Review 96-04, September 1996.

Fowler, Bruce W., "Towards a Formal Theory of Aggregation," submitted for publication to MOR, 1997.

Liao, S., "The Learning Curve: Wright's Model versus Crawford's Model," *Issues in Accounting Education,* Vol. 3, No. 2, 1988 pp. 302–315.

Moses, O. Douglas, "On the Reliability of Indicators of Learning Curve Model Accuracy," *Journal of Cost Analysis,* Spring 1995, pp. 66–67.

Schenk, A., D. W. Hoffmans, H. J. Pasman, and L. A. C. M. Coopmans, "The Use of a Special Win Factor in Army Corps Simulations as applied to attrition issues," in Reiner K. Huber, ed., **Systems Analysis and Modeling in Defense,** Plenum Press, New York, 1982, pp. 587–602.

Sherrill, Randy M., **Cost Estimating Techniques,** course materials, Southeastern Institute of Technology, Huntsville, AL.

Taylor, James G., **Lanchester Models of Warfare,** Operations Research Society of America (now Institute for Operations Research and the Management Sciences), Linthicum, MD, March 1983.

Wright, P. T., "Factors Affecting the Cost of Airplanes," *Journal of the Aeronautical Sciences,* 1936, pp. 122–128.

Airborne and Space-Borne Reconnaissance Force Mixes: A Decision Analysis Approach

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OR METHODOLOGY: Multiobjective Optimization

APPLICATION AREA: Decision Analysis Cost Effectiveness Analysis

ABSTRACT

This paper describes an analysis effort initiated by the Joint Requirements Oversight Council (JROC) of the Joint Chiefs of Staff (JCS). Decision analysis techniques, to include Multi-attribute Value Analysis and Cost-Benefit Analysis, were used to develop a methodology for the evaluation of alternate reconnaissance force mixes.

Given the importance of joint reconnaissance to today's operational commanders and increasing reliance on reconnaissance for the future, the JROC recognized in 1995 that it had no means to make force mix decisions in terms of end-to-end platform capability and cost across all components: manned, unmanned, and overhead. To fulfill this need, the JROC created the Reconnaissance Study Group (RSG) and tasked it to develop and implement a process for making timely and informed reconnaissance force mix decisions.

This paper describes an innovative methodology for determining the composition of promising reconnaissance architectures at various levels of investment for the 2010 time frame. The unique aspects of the approach are its *broad scope and scalability* in addressing the multiple components of the architecture, the use of *value assessments* based upon simulations as well as subjective expert judgment to provide *traceability and repeatability,* and its treatment of *cost as an independent variable* (Rush, 1997) in the cost-benefit analysis of future force mix options.

BACKGROUND

The purpose of this analysis was to develop and implement a process for making timely and informed reconnaissance force mix decisions for airborne and spaced-based platforms. Given the importance of joint reconnaissance support to today's operational commanders and increasing future reliance on reconnaissance, the Joint Requirements Oversight Council (JROC) of the Joint Chiefs of Staff recognized in 1995 that it had no means to make force mix decisions in terms of end-to-end platform capability and cost across all components: manned, unmanned, and overhead. To fulfill this need, the JROC created the Reconnaissance Study Group (RSG), comprised of flag officers representing the Services and key agencies. The JROC tasked the RSG to develop and implement a process for making timely and informed reconnaissance force mix decisions.

The JROC requested that the RSG focus on future requirements and capabilities in a time frame no earlier than 2005. The JROC was particularly interested in the effort to define criteria and metrics for force structure discrimination and evaluation. In accordance with the JROC's guidance, the following parameters were agreed upon:

- The scope of the analysis would include unmanned, manned, and overhead reconnaissance collection platforms as well as exploitation and dissemination systems.
- *All military tasks* to which reconnaissance systems contribute would be considered, not just two Major Regional Conflicts (MRCs).
- The 2010 time frame would be used for both requirements and available capabilities and technologies.
- A set of possible reconnaissance force mixes would be developed with sufficient breadth to enable robust insight into possible budget cuts.
- Unlike most reconnaissance studies, this analysis would be *scenario-independent.*
- The analysis would have an operational focus with reconnaissance requirements being generated by users (Unified Commands, Services, and Joint Staff representatives).
- Cost and benefit to the user would both be independent variables in the analysis; lower cost solutions for reconnaissance force mixes would be of particular interest.

The three major objectives of the analysis were:

- *Establish an initial capability* to assess force mix trades.
- Develop a decision support method that provided *benefit and cost comparisons* of reconnaissance systems in terms of the *overall satisfaction of requirements.*
- *Provide promising, candidate force mixes* that could be subjected to further analysis of different types, including detailed modeling and simulation in specific scenarios.

Finally, there were four critical issues in the design of the analysis that had to be resolved: (1) how should the architecture building blocks for reconnaissance force mixes be designed so that both creative and exhaustive sets of force mixes could be de-

fined and analyzed in a reasonable amount of time? (2) how should modeling be used to aggregate concepts in appropriate places in order to achieve 80% of the desired effect (e.g., precision, accuracy) with only 20% of the mathematical detail? (3) how and from whom should the judgmental inputs be obtained so that they were considered valid? and (4) how should the results be presented so that they are meaningful to the decision makers?

This study developed an analytic process and preliminary analysis recommendations. This paper focuses on the analysis process because the results are classified and were not ends in themselves but have been fed into other decision making process. The detailed results are contained in "Final Report on the Reconnaissance Study Group Cost-Benefit Analysis of Airborne and Space-Borne Reconnaissance Force Mixes" (1996).

METHODOLOGY OVERVIEW

The analysis process, consisting of the six steps as shown in Figure 1, was briefed to the JROC prior to the study and approved by them for implementation. The RSG monitored the study and approved the study's activities at every step. The six steps were:

1. Develop and prioritize the mission-driven tasks and intelligence functions (requirements criteria tree in Figure 1),
2. Develop "metrics" for evaluating architectures on the tasks,
3. Identify reasonable and innovative "architectural packages",
4. Evaluate the alternate architectures on the metrics (assess capabilities),
5. Develop a cost model and evaluate costs of the architectures (cost data),
6. Perform a "cost-benefit analysis" of the alternate architectures.

The analysis process integrates subject matter experts (system operators and information users), quantitative data, qualitative judgments, and tools into a structured and orderly process to provide timely and meaningful insight and trends to senior decision makers on the relative costs and benefits of reconnaissance alternate architectures. Each step is described in more detail.

Step 1. Develop and Prioritize the Mission-driven Tasks and Intelligence Functions

We began by considering all military applications for reconnaissance that were found in the 1995 *National Security Strategy* and the 1995 *National Military Strategy*. At the highest level, there are four support elements: *political, informational, military,* and *economic.* The focus of this study was on military effectiveness includ-

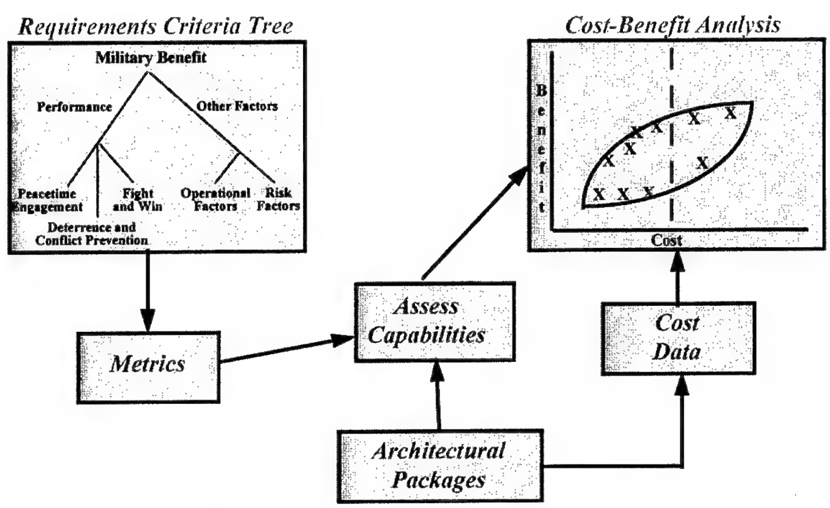


Figure 1. Overall Decision Methodology

ing performance issues, other factors, and risk. Performance was examined in three categories: *peacetime engagement, deterrence and conflict prevention*, and *fighting and winning the joint conflict*. Each of these categories was broken down further into tasks, intelligence functions, and metrics. During this first step the emphasis was placed at the task level.

Figure 2 shows this hierarchy down to the task level. The numbers reflect the relative importance of improving the reconnaissance performance from minimum acceptable to desired in each task; all of the relative swings in importance at the task level sum to 100. For example, performance was given 80% of the weight; the 80% was allocated as almost 10% to peacetime engagement, almost 31% to deterrence and conflict prevention, and slightly more than 39% to fight and win the joint conflict. The allocation of these weights to the next lower level is shown in Figure 2. The decimal points are an artifact of the normalization process and are not intended to show undo precision in the weighting process, which was the consensus judgment of representatives from each CINC.

The category of "Other Factors" was added to capture issues that were specifically part of the military tasks, intelligence functions and associated metrics. In particular, there were three categories of operational factors (operational constraint such as overflight of other countries, logistics issues, and political issues). Finally risk factors were identified but not disaggregated because there is too much interaction among cost, schedule and performance risk.

To achieve agreement on the structure shown in Figure 2 and elicit the weights, a three-day *decision conference* was held with representatives from the following organizations:

- CINCs (ACOM, CENTCOM, PACOM, SOCOM, SOUTHCOM, STRATCOM, SPACECOM);
- Services (Army, Navy, Marine Corps, Air Force);
- Joint Staff (J2/J8);
- Agencies (NSA, CIO, NRO, DARO, DIA, CISA, DMA, BMDO);
- Program Offices.

Decision conferences (see Watson and Buede, 1987; Buede and Bresnick, 1992) are intensive, facilitated working sessions that use quantitative models to capture qualitative judgments. The weights were assessed from the

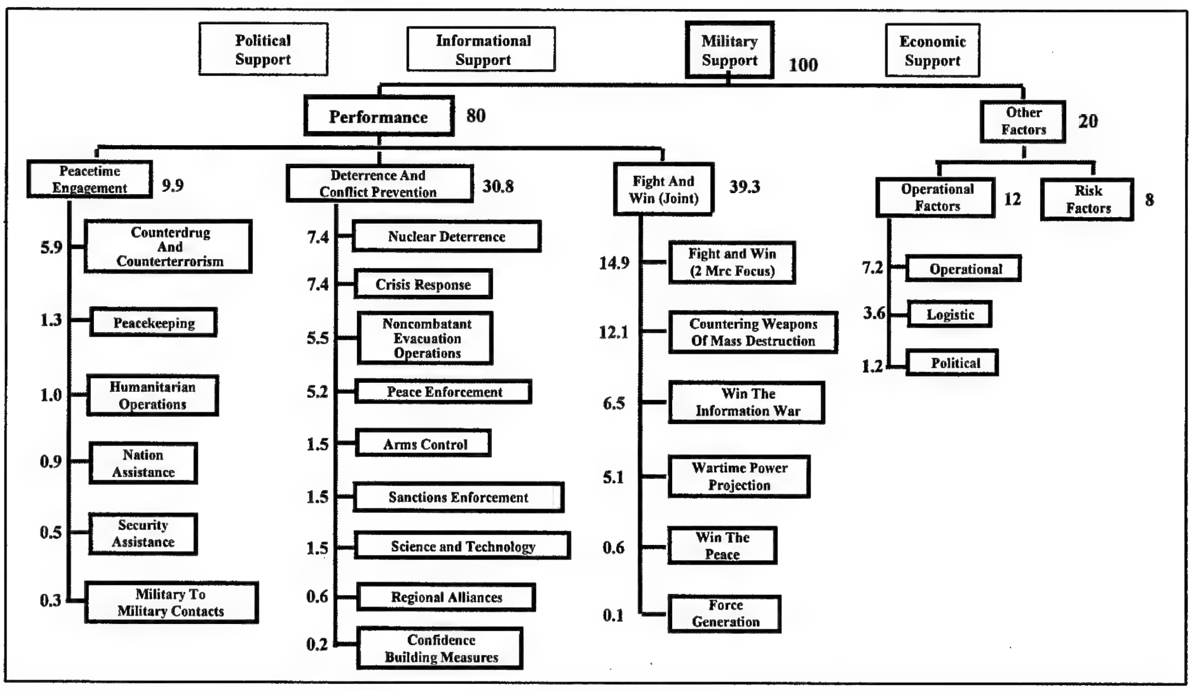


Figure 2. Value Tree

"bottom-up" using an indirect assessment technique called the balance beam (Watson and Buede, 1987). This technique uses conjoint analysis to establish relationships between the weights of groups factors and then infer numerical weights from the relationships. The participants were asked to agree on the relationships through a period of discussion and voting where needed to resolve disagreements. The weights reflect three considerations: (1) how important will the requirement be to the nation in 2010; (2) what is the probability of occurrence of the requirement in 2010; and (3) how relevant are reconnaissance systems to accomplishing the tasks and intelligence functions? Thus, a very important requirement could receive a low weight in this analysis if reconnaissance had little to contribute.

Step 2. Develop Metrics for Evaluating Architectures on the Tasks and Intelligence Functions

For each performance task, key intelligence functions were identified to include *intelligence preparation of the battlefield, targeting, battle damage assessment, indications and warning, situation awareness,* and *mapping/charting/geodesy.* These intelligence functions were defined on the basis of research ("Assured Support to Operational Commanders", 1994; and "Future National Intelligence Review", 1992) and consultation with the participants of the second decision conference, who were largely the same as the participants of the first decision conference.

Relevant metrics for each intelligence function were selected from the set of metrics shown in Table 1.

A second three-day decision conference was held in which a "strawman" set of intelligence functions and metrics for each bottom level entry in Figure 2 was presented to the participants for review and revision. Before an evaluation of the architectures was performed, each metric was defined in detail to ensure that the participants had a common understanding of how system capability would be assessed.

One of the key analytical challenges was "how much modeling is enough?" Clearly, we could have evaluated every architecture on every metric of every reconnaissance function for every task and intelligence function—a massive task. By recognizing that some tasks were much more heavily weighted than others, we developed an "economy of modeling" rule of thumb that reduced the modeling load with little or no impact on results. We categorized the tasks as shown in Table 2.

Table 1. Value Metrics

METRIC TYPE	METRIC
Quality	Level of Detail
	Geolocation Accuracy
Timeliness	Timeliness
	Responsiveness
	Update Frequency
Quantity	Area Coverage (IMINT)
	Point Targets (IMINT)
	Erlangs (SIGINT)
	Signals of Interest (SIGINT)

For highly weighted tasks such as countering weapons of mass destruction, the analysis included all relevant intelligence functions and all relevant metrics for each; for moderately weighted tasks such as wartime power projection, the analysis only included the single most relevant intelligence function and all relevant metrics for the function; and for the lowest weighted tasks such as force generation, the analysis restricted attention to the single most relevant intelligence function and the single, most pertinent metric for that function.

After the metrics were defined, value curves (Watson and Buede, 1987) were needed to measure user satisfaction as a function of system capability. Figure 3 presents an example of a notional performance value curve for timeliness. Each curve relates user satisfaction (expressed on a 0 to 100 point scale) to the performance of a group of reconnaissance systems on tasks and intelligence functions for a specific metric. The RSG analysis used available intelligence community-generated value curves (such as from the *Future National Intelligence Review, 1992*) as well as expert judgment. These curves reflect the notion of decreasing-returns-to-scale common in economics and decision analysis.

For each metric, a family of curves was developed rather than a single curve. Each curve in a family had the same shape and was defined by three points: the maximum satisfaction point that was assigned a score of 100, the minimum satisfaction point that was assigned a

Table 2. Categorization of Military Performance Tasks by Weight

	CATEGORY OF WEIGHT VALUE		
	Low (below 1.5)	Moderate (between 1.5 and 7.4)	High (above 7.4)
PERFORMANCE TASK	Arms Control	Nuclear Deterrence	Fight & Win (2 MRC focus)
	Sanctions Enforcement	Crisis Response	Counter Weapons of Mass Destruction
	Science & Technology	Win the Information War	
	Peacekeeping	Counterdrug & Counterterrorism	
	Humanitarian Operations	Noncombatant Evacuation Operations	
	Nation Assistance	Peace Enforcement	
	Win the Peace	Wartime Power Projection	
	Regional Alliances		
	Security Assistance		
	Military to Military Contacts		
	Confidence Building Measures		
	Force Generation		

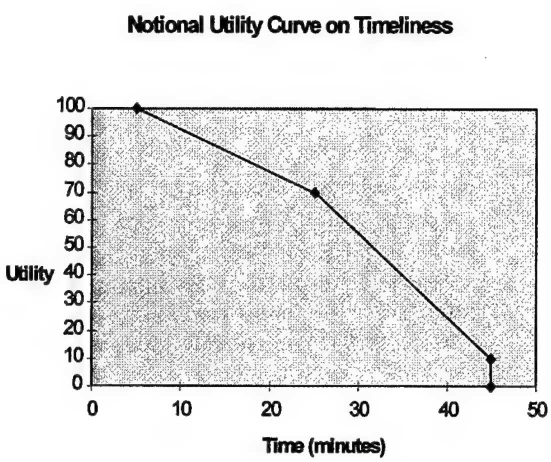


Figure 3. Notional Value Curve for Timeliness

score of 10, and the nominal required capability that was assigned a score of 70. These scores were used in the Future National Intelligence Review (1992); the participants agreed that this structure was acceptable. The curves had slight decreasing returns to scale. Note, any capability below the minimum satisfaction point was given a score of 0. This family of curves recognized that the same capability might be valued differently in different tasks. For example, a timeliness capability of several hours may get 100 value points in a peacetime engagement context, but in a wartime context, timeliness of seconds or minutes may be required to get 100 points.

Value curves were also developed for the "Other Factors" criteria, including Risk.

During the second decision conference the participants reviewed the family of curves available for each bottom level task, intelligence function, and metric and selected the curve judged to be most relevant. In some cases the three points defining the value curve were changed to better reflect the judgment of the CINC, Service, and Joint Staff representatives. This consensus was usually obtained by open discussion followed by general agreement. In cases where there was insufficient agreement, a vote was taken. These participants also provided weights across the intelligence functions and value curves using the same process as was employed during the first decision conference. It is important to note that the value curves were developed independent of the alternatives and should remain valid as new alternatives are introduced in the future.

With the addition of performance metrics and notional value curves for each reconnaissance function, the performance evaluation hierarchy would be as shown in Figure 4 for *Fight and Win the Joint Conflict.* Similar trees were developed for the other elements of Performance for the Other Factors.

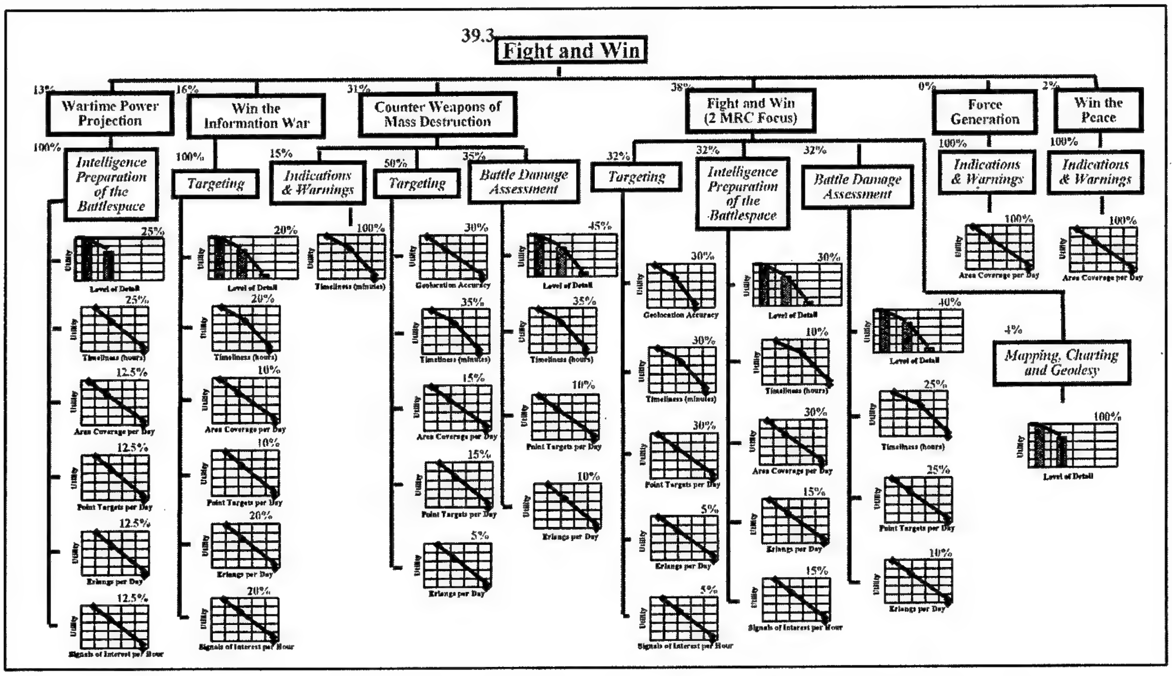


Figure 4. Tasks, Reconnaissance Functions, and Value Curves for Fight and Win

The tree structure now has two main branches for Military Support: performance and other factors. Within the performance branch there are four levels: level of conflict (peacetime engagement, deterrence and conflict prevention, and fight and win), conflict tasks (e.g., nation assistance and wartime power projection), intelligence functions (e.g., targeting and situation awareness), and metrics. For the other factors branch, there are two factors: operational and risk. Operational factors is divided into issues of operations, logistics, and politics. Every metric and the four bottom level branches under other factors had a value curve defined for it.

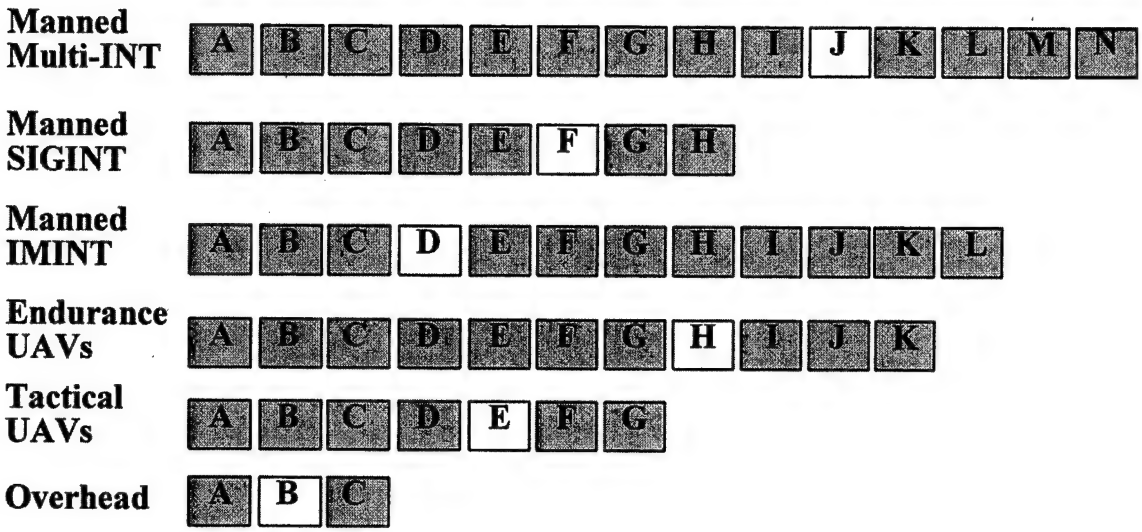
Step 3. Identify Alternative Architectural "Levels"

An architecture refers to a system of systems; in this particular case, to a system of airborne and space-borne reconnaissance platforms, each platform being comprised of one or more systems. For the purposes of this study the reconnaissance platforms were grouped into six distinct components:

- Manned Multi-Intelligence (Multi-INT) platforms
- Manned Signals Intelligence (SIGINT) platforms
- Manned Imagery Intelligence (IMINT) platforms
- Endurance Unmanned Aerial Vehicles (UAV) platforms
- Tactical Unmanned Aerial Vehicles platforms
- Overhead satellites platforms

Figure 5 illustrates how the reconnaissance components were configured for this analysis to represent an overall system of systems architecture. For each component (row), the lettered blocks represent alternate packages (referred to as levels) for the row. An architecture is defined by selecting one package (level) for each row.

Each component package depicted in Figure 5 included "end-to-end" systems (including processing, exploitation, and dissemination systems) as well as the front-end system required to task reconnaissance systems and deliver "products" to users. Each of the packages, i.e., each cell in Figure 5, is itself a *combination* of specific reconnaissance platforms in varying configurations and quantities. Each platform



An architecture = one package from each component (e.g., J+F+D+H+E+B)

Figure 5. Architectural Components

contains the requisite systems needed to complete its missions. For example, the eight manned SIGINT packages shown in Figure 5 might be made up of the notional platforms shown in Table 3. Here, Level A is made up only of System F aircraft and hence is a low cost, bare bones option. Conversely, Level H is made up of sizable quantities from all seven platform types, most of which have upgraded sensors and re-engining, and hence is a highly capable option with associated higher life cycle cost.

A third 3-day decision conference was held to identify the platforms and associated systems that made up each component and the numbers and capabilities of each platform in each package of the components. Each cell of each row in Table 3 then had to be evaluated in terms of its costs and its benefits on all of the value curves.

Table 3. Notional Packages of the Manned SIGINT Component: Comprised of Platform Quantities and Configurations

SYSTEM TYPES	PACKAGES							
	A	B	C	D	E	F	G	H
Platform A	0	0	3*	3	3*	3	0	3*
Platform B	0	8	8*	16	8*	16	16*	16*
Platform C	0	14	24*	30	24*	42	42	42*
Platform D	0	0	0	8	16	16	16*+	16*+
Platform E	0	12	12	6	0	12	12*	12*
Platform F	2	2	2	2	2*	2	2*+	2*+
Platform G	0	3	3	3	3	3	3*+	3*+

* improved sensors
+ re-engining

Step 4. Evaluate the Architectures on the Metrics

The initial effort of evaluating the user satisfaction of each package in each component used a linear-additive scoring rule for combining weights and scores from the value curves. This approach assumed preferential independence of the evaluation criteria at every level of the evaluation hierarchy (Keeney and Raiffa, 1976), which proved to be too general an assumption for the reconnaissance functions and performance metrics. To address specific interactions between platforms, metrics and intelligence functions, a set of scoring rules and assumptions were developed that allowed for combining metrics for each intelligence function in a nonadditive way based upon the dynamic and operational realities of how the systems would be employed (e.g., weather considerations, resource contention, simultaneous tasking, etc.). These scoring rules are summarized in the Appendix. Each assumption and rule was carefully documented and fully

supports the degree of traceability and repeatability of the decision methodology desired by the JROC.

The scoring "rollup" at the level of intelligence function and above assumed a linear-additive scoring rule. This assumption was vetted with the participants of the study and judged to be an appropriate assumption at this level of the hierarchy. The rollup on the performance hierarchy was done in an extensive set of interactive spreadsheets. Thus, it was straightforward to use the scoring methodology and the spreadsheet file to examine a broad range of available simulation results and different assumptions on system capability. This technique also guaranteed consistency and repeatability of the results. The output of the scoring process was a single benefit score for each level of each architectural component for each of the three performance areas: *peacetime engagement, deterrence and conflict prevention, and fight and win the joint war.*

Scores for the "Other Factors" criteria were assessed directly from the value curves developed for those criteria for each package of each component. For example, each package was scored on risk. Packages with only existing platforms were scored highest. Packages with platforms for which program offices were not yet defined were scored lowest. The weighted average for "Other Factors" assumed a linear-additive scoring rule, which was also judged to be appropriate for these criteria by the participants of the study.

To summarize the equation for computing the benefit for each package in each component of a possible architecture was:

$$B = w_p\left(\sum_i \sum_j \sum_k w_{C_i} w_{T_{ij}} w_{IFijk} S(C_i, T_{ij}, IF_{ijk})\right) + w_{OF}(w_{OpF}(w_O S_O + w_L S_L + w_p S_p) + w_R S_R)$$

where

w_{P} = weight for Performance
w_{Ci} = weight for Conflict category i
w_{Tij} = weight for Task j in Conflict category i
w_{IFijk} = weight for Intelligence Function k in Task j in Conflict category i
w_{OF} = weight for Other Factors
w_{OpF} = weight for Operational Factors
w_{O} = weight for Operational Issues
w_{L} = weight for Logistics Issues
w_{P} = weight for Political Issues
w_{R} = weight for Risk Factor
$S(C_i, T_{ij}, IF_{ijk})$ = Value Score on Intelligence Factor k of Conflict I and Task j
S_O = Value Score on Operational Issues
S_L = Value Score on Logistics Issues
S_P = Value Score on Political Issues
S_R = Value Score on Risk

Step 5. Develop a Cost Model and Evaluate Costs of the Architectures

The major objective of the cost analysis was to capture "end-to-end" reconnaissance system Life Cycle Costs (LCCs) from 1997 through 2020. For this analysis, the end-to-end use of a system was defined as the systems (ground and airborne/overhead), maintenance, and manpower required to direct the system's data collection activity, execute the data collection, disseminate the raw data, and analyze and redirect the data collected by the system. To accomplish this goal, system development, procurement, and operations and support (O&S) costs for each platform configuration (including upgrades) were computed and aggregated based upon the number of platforms. In addition, the costs of the associated ground stations and additional airborne assets needed to execute the mission were computed and proportionally added to the platform costs.

A second critical goal of this effort was to develop a comprehensive and traceable reconnaissance LCC development approach that would provide consistent and comparable LCC estimates for each level in the RSG cost-benefit analysis. The approach provided visibility into all the cost estimating parameters, such as first unit costs, learning curve effects, costs per flying hour, and pre-planned product improvement (P3I) costs, and global parameters, such as prior quantity, procurement quantity, average annual flying hours, etc. The approach provided the ability to perform "what-if" excur-

sions around these parameters for sensitivity analysis and the capability to add or mix configurations.

The key challenge was to obtain consensus on these end-to-end LCC positions from representatives associated with each system included in the analysis. A one-day decision conference was held on costing issues. Based upon data provided or sanctioned by these representatives, reasonable LCC positions were developed that attained this consensus. The conference was followed by an open review of all of the LCC positions by the representatives from each system. Disconnects and disagreements were discussed and new LCC positions were developed as needed. The output of the costing process was a single LCC for each package of each architectural component.

Step 6. Perform a Cost-Benefit Analysis of the Architectures

Once a cost and a benefit measure was determined for each level of each architectural component, a cost-benefit analysis using a Pareto-optimal, efficient frontier approach was completed to determine the best allocation of resources across all components (Buede and Bresnick 1992). Commercial off-the-shelf software called EQUITY was used to develop a "1" to "n" list that achieves the most bang for the buck at increasing LCC points. See Watson and Buede (1987) for a discussion of this approach and Kirkwood (1997) for a more general discussion of this topic. The major assumption made here is that both the cost and benefits associated with a given component were independent of the packages chosen on other components.

An alternate architecture is defined by selecting one package from each architectural component. The small circle in the center of the football in Figures 6a and 6b represents a single architecture. For any budget target, it is clear in Figure 6b that the most benefit is achieved if there is an architecture along the top of the football that is near the budget amount. If the dot architecture in Figure 6b has a LCC of C, then architecture X, which also costs C, gets more "bang-for-the-buck". There is also an architecture Y that gets the same benefit as the dot architecture but is significantly cheaper. There are more than 310,000 possible architectures based upon the 14, 8, 12, 11, 7 and 3 packages in the six components, see Figure 5. These 288,000 plus architectures have the "nice" mathematical property of falling into a football shaped region in the LCC and benefit space, called the Pareto-optimal space as shown in Figure 6a. For any proposed architecture that falls within the football shaped region, there is a better (X) and cheaper (Y) way to spend the same amount of resources as shown in Figure 6b.

This analytical approach focuses on finding the architectures along the top of the football. This "efficient frontier" establishes the best order-of-buy of packages in the architectural components; this order-of-buy is called the convex hull in mathematical programming. It is calculated by taking the incremental benefit in going from one package to the next in a row

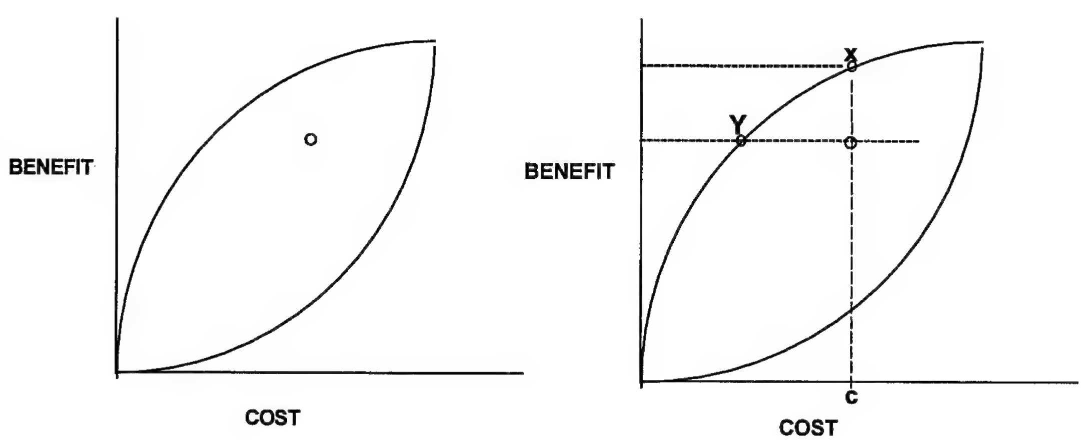


Figure 6a. A Single Architecture (the small circle), The Pareto-Optimal Space, and the Efficient Frontier
Figure 6b. Better and Cheaper Solutions

and dividing by the incremental cost, then ordering the ratios from best to worst. This "marginal" analysis provides far more insight into achieving efficiencies than simply calculating total benefit/cost ratios. There were 54 different optimal increments out of the more than 288,000 possible architectures. On the basis of this optimal order we plotted the total LCC and benefit of each of the 54 optimal architectures on the convex hull of the Pareto-optimal, or efficient, frontier. Decision makers refer to it as the top of the football. Note this analysis process did not compute all of the Pareto optimal architectures that fell between each pair of points on the convex hull. The purpose of this analysis was not to determine the optimal way to spend a pre-defined amount of money, but rather to provide insight into the sets of packages that were near the optimal allocation of life cycle cost during the timeframe of the study.

A final 3-day decision conference was held, and using the benefits and costs assessed earlier, we developed the "football" for the reconnaissance mix as shown in Figure 7.

Since the conclusions of the study have not yet been finalized at the JROC level, no specific results will be discussed here. However, it is clear that the methodology presents a straightforward way to investigate architectures that are near the "knee of the curve", thus achieving a very efficient use of resources. By varying the weights on the evaluation factors, we performed extensive sensitivity analyses and developed various footballs for different worldwide scenarios.

CONCLUSIONS

The combined multi-attribute value, Pareto-optimality approach, implemented in a decision conferencing framework is a viable methodology for end-to-end analysis of military systems. It reveals alternatives that may offer substantial economies without significant loss in benefit, as well as alternatives that get more benefit for the same level of expenditure. The approach can be used to achieve consensus by bringing together operators (CINC and Service representatives), requirements managers, and systems developers.

The Background section stated that there were four issues that needed to be resolved as this analysis proceeded.

- ***How should the architecture building blocks for reconnaissance force mixes be designed so that both creative and exhaustive sets of force mixes could be defined and analyzed in a reasonable amount of time?*** This issue was resolved by breaking the total set of reconnaissance resources into the six components defined in Figure 5. At the end of the analysis

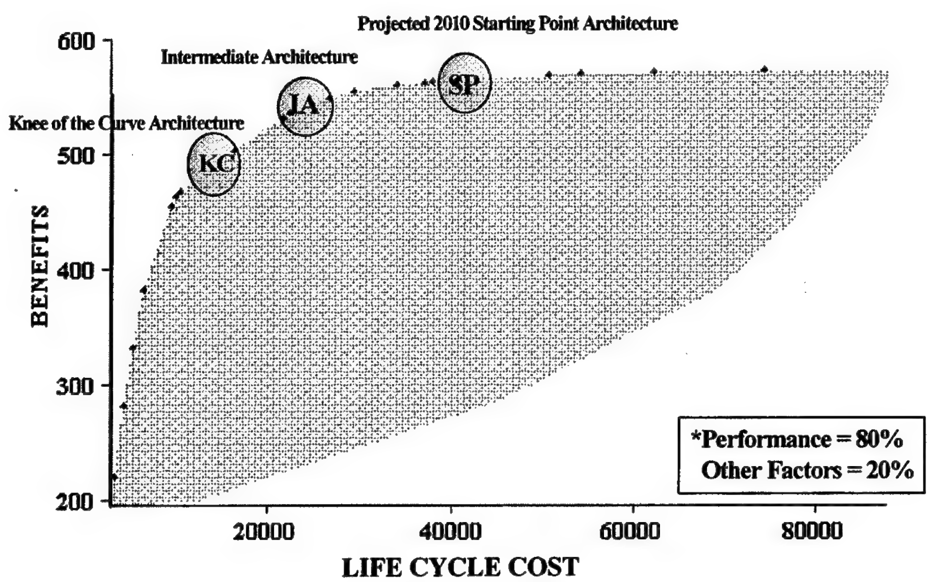


Figure 7. Cost-Benefit "Football" for reconnaissance Mixes

the study team had a long debate about whether this division could have been improved. There were arguments for and against defining many more components although everyone agreed that it would have been a big mistake to have allowed each platform to be its own component; the logic for this conclusion was that there was too much redundant capability among many of the platforms and this detailed division would have greatly over valued the architecture. Since the main issue with this analysis was that the architecture as a whole seemed to be overvalued (see Step 4, Figure 7, and the appendix), there was a strong argument for even fewer components than the six that were defined. However, even after the discussion the group was unable to develop a different set of components that everyone agreed would have been better. This was a key to a successful and valid analysis.

- ***How should modeling be used to aggregate concepts in appropriate places in order to achieve 80% of the desired effect (e.g., precision, accuracy) with only 20% of the mathematical detail?*** Here the study group felt that the decisions to limit the intelligence functions and metrics for conflict tasks with low and moderate weights were valid aggregations and did not detract in any way from the final results. In addition, there were key uncertainties that were embedded in the judgmental inputs. More explicit representation of these uncertainties would have been very valuable.
- ***How and from whom should the judgmental inputs be obtained so that they were considered valid?*** The process of convening military and civilian representatives from the key military commands and government agencies worked very well. These representatives were knowledgeable and were willing to rise above the parochial interests of their own organization and address the overall value to military support. In addition, these representatives were able to maintain continuity across all of the conferences so that valuable time did not have to be devoted to revisiting old issues. The consensus of these participants was that this analysis process was an important and valuable approach to examining force mix decisions.
- ***How should the results be presented so that they are meaningful to the decision makers?*** The football analogy and the order-of-buy listing proved to be useful to communicating the results to flag officers with little time to dig into the analysis details. The concept of breaking the reconnaissance architecture into six components, with each component having several platforms was easy to understand.

The strengths of the method are that:

- **It works**—it is scaleable in time and dollars; it isolates the key and viable decision alternatives (i.e., it gets to the "80% solution" quickly); it captures the impact of cost and military benefit; and it produces traceable rationale.
- **It builds consensus among participants**—it accommodates both expert judgment and quantitative performance data; it addresses the "soft" factors in decision making; it uses both a top-down approach to achieve a structured, broad view and a bottoms-up approach to get the necessary levels of detail; it facilitates sensitivity analysis on key parameters; and it is easy to re-execute using different data sets or assumptions.

The methodology also has its limitations:

- The results are no better than the quality of people and data involved in the process;
- It can require a large number of judgments;
- It imposes some assumptions of benefit and cost independence among the rows that may not be true in the real world; and
- It can take a lot of time and effort.

As with most operations research problems, there were the analytical challenges that we had to face, but there were also the "real-world" challenges that were even more difficult. These included:

- ***How do we get many organizations that are competing for resources, particularly organizations that have not always worked well together, to put parochialism aside and think "corporately"?***—the decision conference provided the forum for all organizations to be heard and to present their positions, to exchange information openly, and to work towards informed consensus. Additionally, using a quantitative framework took much of the emotionalism out of the debate. Bringing the right people to the table is always a key to success. We were fortunate to have senior level, forward thinkers who

did, in fact, defend their own positions yet were willing to think "jointly" as well.

- ***How do we deal with a massive number of issues, judgments, and measurements within the limited time frame and scope of the analysis?***—the key here was "economy of modeling". By applying the same Pareto techniques used in the approach to our analytical efforts, we could get to the 80% solution quickly, and then decide where it was worth our effort to model more extensively. We constantly had to fight the urge to "get more data", and we had to remain on a course to reach a recommendation before the problem had changed.
- ***How do you keep people from believing too much in the computerized numerical results?***—Once people get involved with the inertia of the modeling activity, it is too easy to accept results that come out of the back end. Each step of the way, we had to apply a "gut check" to the results, and if they didn't pass, we had to determine why. This necessitated revisiting assumptions, making scoring rules more specific, and developing innovative modeling approaches for areas that had not been previously modeled. Flexibility and adaptability were key ingredients along with a well-documented audit trail of rationale which is often more important than the numerical results themselves.

On balance, this effort allowed us to merge people, process, and data to:

- Provide insight that is both timely and meaningful to senior decision makers as to the relative worth of competing military support tasks and intelligence functions;
- Validate a methodology for a broad and complex problem; and
- Illuminate policy issues and relationships between specific systems, costs, and levels of user satisfaction.

We believe that it is a viable methodology for future efforts.

Acronyms

BMDO—Ballistic Missile Defense Office
CIO—Central Imagery Office
DARO—Defense Airborne Reconnaissance Office
DIA—Defense Intelligence Agency
DMA—Defense Mapping Agency
IMINT—Imagery Intelligence
IPB—Intelligence Preparation of the Battlefield
ISR—intelligence, surveillance, and reconnaissance
JCS—Joint Chiefs of Staff
JROC—Joint Requirements Oversight Council
LCC—Life Cycle Cost
MRC—Major Regional Conflict
Multi-INT—multi-source intelligence
NRO—National Reconnaissance Office
NSA—National Security Agency
O&S—operations and support
P3I—pre-planned product improvement
RSG—Reconnaissance Study Group
SIGINT—Signals Intelligence
UAV—Unmanned Aerial Vehicles

Acknowledgement

Many people participated on the analysis team for this effort. The government program manager was Colonel Michael Fagan (USMC). The analysis team was led by LTG Norm Ehlert (ret.). Al Pisani managed the programmatic effort, and was assisted by John Kelsey. Buddy Wood, Terry Bresnick and Dennis Buede led the cost-effectiveness structuring, elicitation and analysis. The technical analysis of systems, missions and scenarios was conducted by Hank Barrows, Ken Cogan, Dick Goebel, Leighton Smith, and Barry Thomas. Dan Cottrell developed the detailed spread sheet for computing the benefit scores of the architectural components. Kirk Hoy performed the cost analysis. Many active duty military and many government civilians provided the expertise needed for this effort; their contributions were crucial to this analysis.

The authors would like to thank the anonymous referees for their many and valuable comments; this paper is much better due to the suggestions that they made.

REFERENCES

Buede, D.M. and Bresnick, T.A. 1992, "Applications of Decision Analysis to the Military Systems Acquisition Process", **Interfaces,** Vol. 22, No. 6, pp. 110–125.

Joint Chiefs of Staff. 1995, "National Military Strategy." ISBN 0-16-045531-6.

Keeney, R.L. and Raiffa, H. 1976, Decisions with Multiple Objectives: Preferences and Value Tradeoffs, New York: Wiley.

Kirkwood, C. 1997, Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets, Belmont, CA: Duxbury.

National Security Council. 2 March 1995, "Presidential Decision Directive/NSC-35".

Rush, B.C. 1997, "Cost as an Independent Variable: Concepts and Risks," **Acquisition Quarterly Review**, Vol. 4, pp. 161–172.

TASC. 30 September 1996, "Final Report on the Reconnaissance Study Group Cost-Benefit Analysis of Airborne and Space-Borne Reconnaissance Force Mixes," TASC Final Report.

The White House. February 1995, "A National Security Strategy of Engagement and Enlargement." OCLC# 32113379.

US Defense Intelligence Agency. July, 1994k, "Assured Support to Operational Commanders." CC-2600-6418-94.

US Government. 1992, "Future National Intelligence Review (U)."

Watson, S.R. and Buede, D.M. 1987, *Decision Synthesis: The Principles and Practice of Decision Analysis*, Cambridge, England: Cambridge University Press.

Appendix

The scoring process developed eight scoring rules to account for the complexities of scoring a package vice a single platform. This was complicated by the fact that all platforms did not have a one-to-one correlation in benefit and therefore the benefit of each platform could not be simply aggregated. The following rules accounted for these complexities:

1. ***Weighted Average Rule:*** When appropriate, an individual platform's contribution to a package's score for Quality and Timeliness metrics, was weighted based upon the platform's quantity performance. If a platform scored high on a Level of Detail curve but contributed only 25% of the Area Coverage, its contribution to the overall Level of Detail score was reduced to 25% of what it would have been. This precluded package scores from being overinflated due to unrealistic package performance.
2. ***Residual Value Rule:*** If a platform did not contribute at least the Residual Value (10%) of the Required Value, then its contribution to that package was not counted in the benefit score. In other words, if a platform scored high in Geolocation Accuracy but contributed less than the specified Residual Value in Area Coverage, then its contribution toward that package was not included. This precluded the contribution to overall package score from a platform that stood no likelihood of ever being used.
3. ***Nuclear Deterrence Rule:*** The overall airborne contribution in the Nuclear Deterrence military performance task was decreased to 10% and the overhead contribution was decreased to 20%. This was done to capture the unavailability of a platform to collect necessary information.
4. ***Targeting Rule:*** Most SIGINT platforms had minimum contribution to scores when the Targeting (TGT) intelligence function was selected. This was done to preclude contribution to overall package score by platforms that normally would not be used to support Targeting.
5. ***BDA/MC&G Rule:*** For current platform capability and CONOPS, SIGINT contribution to the Battle Damage Assessment (BDA) intelligence function was decreased to 10%. Also, for the one case where the Mapping, Charting, and Geodesy (MC&G) metric was selected, SIGINT was not scored. This was done to preclude contribution to overall package score by platforms that normally would not be used to support BDA or perform MC&G missions.
6. ***Multi-INT Rule:*** The Multi-INT platforms were scored if they were able to achieve the Residual Value or greater by either its SIGINT or IMINT capability, or both. If the Multi-INT platform could not meet the SIGINT requirements because of the Residual Value Rule (see Rule #2, above), yet was able to meet or exceed the IMINT requirements, then IMINT credit was accounted for in the scoring. This provided appropriate credit to the multi-functional platforms for being able to use whatever sensors that were on board to satisfy the requirements of a given mission.

7. ***Allocation Rule:*** A platform quantity contribution was based upon the weights of the intelligence function. If a collector could collect 140 Point Targets in support of a military task, and the intelligence functions selected for that task were weighted 30% IPB, 40% TGT, and 30% BDA, then those 140 Point Targets were distributed to those tasks proportionately. (Namely, 42 Point Targets to IPB, 56 Point Targets to TGT, and 42 Point Targets to BDA). This compensated for the dynamic that in a performance task where multiple intelligence functions are being scored, it was infeasible that platforms would be tasked in a sequential manner, rather they would be utilized nearly simultaneously.
8. ***Exclusion Rule:*** If a platform would never contribute to a task, then it was not scored. This precluded a platform from scoring in a task where it never would be used.

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AIR FORCE 2025 OPERATIONAL ANALYSIS

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Lt Col Jack A. Jackson is the Director of the Center for Modeling, Simulation & Analysis at the Air Force Institute of Technology. He is a command pilot whose recent assignments include flying fighters in USAFE and as a tactical fighter/weapons analyst in the Pentagon. His teaching and research interests include decision/economic analysis, math programming, applied statistics, and combat modeling.

Dr. Gregory S. Parnell teaches OR at Virginia Commonwealth University and consults with Toffler Associates, a strategic advisory firm. He has extensive Air Force experience as a research and development manager and a operations research analyst. He is a former President of the Military Operations Research Society and is a Fellow of the Society. His teaching, research, consulting interests focus on decision & risk analysis. He jogs every day the sun comes up.

Lt Col Brian L. Jones is currently Chief of the Technology Division at the National Air Intelligence Center. He has extensive Air Force experience in aerospace science and technology, aircraft flight test, and manned spacecraft operations. He led the Technology Team for the Air Force Chief of Staff directed *Air Force 2025* strategic study. His current research interest and writings address the relationship between military strategy, doctrine and technology development.

Major Lee J. Lehmkuhl is an Assistant Professor and Operations Research Division Chief at the Department of Mathematical Sciences, United States Air Force Academy. As a career Air Force officer and analyst, he has applied OR to military problems in such areas as space, logistics, and campaign planning. His research and consulting interests tend toward optimization and decision analysis, and personal interests involve enjoying the Colorado outdoors with a variety of implements, a fly rod being just one.

Major Harry W. Conley leads the modeling team in the Joint Simulation System Joint Program Office in Orlando, Florida. He has worked in the military simulation field for fourteen years, including a tour at Air Force Studies and Analyses Agency, where he was lead analyst on several USAF strategic studies. He spent two years in Seoul on the Combined Forces Command staff, where he was the command's air analyst. He has a M.S. in Operations Research from the Georgia Institute of Technology, and a B.S. in OR from the US Air Force Academy.

Colonel John M. Andrew is the deputy commander of the Air Force Agency for Modeling and Simulation. His diversified OR career includes stints in operational test and evaluation, personnel analysis, teaching at the Air Force Academy, and a research fellowship at the RAND Corporation. He was also a member of the staff group of the Secretary of the Air Force. He occasionally conducts trajectory analysis studies at local golf courses.

APPRAISING WARFIGHTING CONCEPTS WITH WARGAMING SIMULATIONS

by Robert M. Chapman

Robert Chapman holds a BS from the United States Air Force Academy and an MA from the University of Michigan, both in Economics. He is a retired Air Force pilot with combat experience in fighters and several assignments in operations research-related billets. Now employed by AB Technologies at Headquarters, Air Combat Command, he is developing ACC's Distributed Mission Training Program. DMT is a revolutionary aircrew training system that will link advanced flight simulators and constructive war games in a distributed, synthetic battlespace. At the time he wrote the article appearing in this edition, he was at the Joint Warfighting Center employed by Cubic Applications Inc. In that capacity, he supported JWFCs' joint exercise program and Joint Simulation Systems (JSIMS) effort.

CONCEPT EXPLORATION ON THE VIRTUAL BATTLEFIELD

by Gary Q. Coe

Gary Coe is a research staff member with the Institute for Defense Analyses. He currently is directing the evaluation of the Synthetic Theater of War 97 Advanced Concepts Technology Demonstration and served the Defense Board in its 1996 Summer Study on Tactics and Technology for 21st Century Military Superiority. He is a retired Army Colonel.

THE COST EXCHANGE RATIO: A NEW AGGREGATE MEASURE OF COST AND OPERATIONAL EFFECTIVENESS

by Bruce W. Fowler and Pauline P. Cason

Dr. Bruce W. Fowler is Technical Director and Deputy of the Advanced Systems Concepts Office, Missile Research, Development, and Engineering Center, U. S. Army Aviation Missile Command, Redstone Arsenal, AL, and Adjunct Associate Professor of Physics at the University of Alabama in Huntsville. He has been active in

the technical and operational development and assessment of advanced weapons concepts for over twenty years. Dr. Fowler holds a B.S.Ch.(Chemistry, Physics, and Mathematics) from the University of Alabama in 1970, an M.S.(Physics) from the University of Illinois in 1972, a Ph.D. (Physics) from the University of Alabama in Huntsville in 1978, and is a graduate of the U. S. Army War College in 1990. He is a member of the Army Acquisition Corps and is accredited SPRDE Level 3.

Dr. Pauline Cason is Program Manager for the Systems, Cost, Risk, and Program Evaluation Support Contract for the US Army Aviation and Missile Command. She is employed at Science Applications International Corporation. Dr. Cason formerly held positions within the Department of the Army as Director of Command Analysis at the US Army Missile Command and as Director of Financial Analysis in the Office of the Assistant Secretary of the Army (Financial Management). She holds degrees in Business Administration and Public Administration from the University of Alabama in Huntsville and a Doctorate for Business Administration from NOVA University, Ft. Lauderdale Florida. She has over twenty years experience in business, financial, and operations research analysis. She has published in a variety of professional journals and taught at the undergraduate and the graduate level.

AIRBOURNE AND SPACE-BOURNE RECONNAISSANCE FORCE MIXES: A DECISION ANALYSIS APPROACH

by Terry A. Bresnick, Dennis M. Buede, Albert A. Pisani, Leighton L. Smith and Buddy B. Wood

Mr. Terry Bresnick is the President of Innovative Decision Analysis. Earlier, as an officer in the U.S. Army, and currently, as a consultant in the private sector, Mr. Bresnick has had extensive experience in applying decision analysis, risk analysis, strategic planning, resource allocation, evaluation techniques and cost-benefit analysis to the problems of government and industry. He has been an Assistant Professor of Systems and Decision Analysis at the U.S. Military Academy, and is a registered Professional Engineer in the State of Virginia. Mr. Bresnick is a previous winner of the David Rist Prize by the Military Operations Research Society. Mr. Bresnick hopes that he can continue to do operations research work for many more years and that he will never have to get a real job.

Dennis Buede has done extensive research in the fields of decision analysis, data fusion and systems engineering. In particular, he has pioneered in the development of new decision methodologies in the areas of system design and evaluation, and resource allocation. He has co-authored a book titled *Decision Synthesis*, authored or co-authored numerous professional and technical papers in the above fields, and is currently writing a book titled *The Engineering Design of Systems: Methods and Models*. He has become a much better writer since joining academia in 1991.

Al Pisani has over fourteen years of progressive experience and responsibility in the management, application, and presentation of quantitative analysis of support business process improvements, systems architecture development, and cost-effective resource allocation decisions. He has extensive experience in designing and implementing cost-benefit, affordability assessments and organizational process reengineering projects for the DoD and Intelligence communities. Strong, persuasive presentation skills, operates at very senior executive levels, a recognized company leader with vision and an accomplished business builder with a commitment to customer support. Al is the father of three boys under the age of six and does not have the opportunity to author very many articles.

Leighton Smith is an industrial engineer with extensive experience in solving complex, multifaceted real-world problems. He has designed more than twenty unique system analysis solutions to his credit. He has been a principal investigator on projects for NASA/Kennedy Space Center, U. S. Air Force, U. S. Navy, U. S. Army, the Office of the Secretary of Defense, United Agricultural Products, and various other U. S. government organizations and commercial businesses. He is an accomplished author with nearly 300 products ranging from technical articles, plans, and two novels (with a third underway). His hobby is "collecting" vocabulary words.

Buddy Wood has over twenty five years experience applying operations research and decision analysis methods to complex problems in defense and intelligence. A recent focus has been multi-attribute utility analysis to support best value acquisition of intelligence architectures. Mr. Wood is author of numerous professional and technical papers and winner of the Harold Brown award for research in Bayesian test design. Widely recognized as a practitioner who applies analysis to anything and everything, his most recent claim to fame is a Fourier analysis of his electric bills—in which he was able to analytically confirm that there was a summer and winter each year for the past five years.

Editorial Policy and Submission of Papers

EDITORIAL POLICY

The title of our journal is *Military Operations Research*. We are interested in publishing articles that describe *operations research* (OR) methodologies used in important *military* applications. We specifically invite papers that are significant military OR applications. Of particular interest are papers that present case studies showing innovative OR applications, apply OR to major policy issues, introduce interesting new problem areas, highlight educational issues, and document the history of military OR. Papers should be readable with a level of mathematics appropriate for a master's program in OR.

All submissions must include a statement of the major contribution. For applications articles, authors are requested to submit a **letter** to the editor—exerpts to be published with the paper—from a **senior decision-maker** (government or industry) stating the benefits received from the analysis described in the paper.

To facilitate the review process, authors are requested to categorize their articles by **application area** and **OR method**, as described in Table 1. Additional categories may be added. (We use the MORS working groups as our applications areas and our list of methodologies are those typically taught in most OR graduate programs.)

INSTRUCTIONS TO *MILITARY OPERATIONS RESEARCH* AUTHORS

The purpose of the "instructions to *Military Operations Research* authors" is to expedite the review and publication process. If you have any questions, please contact Ms. Corrina Ross, MORS Communications Manager (email: morsoffice@aol.com).

General

Authors should submit their manuscripts (3 copies) to:

Dr. Gregory S. Parnell, Editor, *Military Operations Research*
Military Operations Research Society
101 South Whiting Street, Suite 202
Alexandria, VA 22304

Per the editorial policy, please provide:

- authors statement of contribution (briefly describe the major contribution of the article)
- letter from senior decision-maker (application articles only)
- military OR application area(s)
- OR methodology (ies)

Approval of Release

All submissions must be unclassified and be accompanied by release statements where appropriate. By submitting a paper for review, an author certifies that the manuscript has been cleared for publication, is not copyrighted, has not been accepted for publication in any other publication, and is not under review elsewhere. All authors will be required to sign a copyright agreement with MORS.

Abbreviations and Acronyms

Abbreviations and acronyms (A&A) must be identified at their first appearance in the text. The abbreviation or acronym should follow in parentheses the first appearance of the full name. To help the general reader, authors should minimize their use of acronyms. If required, a list of acronyms can be included as an appendix.

TABLE 1: APPLICATION AREAS & OR METHODS

Composite Group	APPLICATION AREA	OR METHODOLOGY
I. STRATEGIC & DEFENSE	Strategic Operations Nuclear Biological Chemical Defense Arms Control & Proliferation Air & Missile Defense	**Deterministic Operations Research** Dynamic Programming Inventory Linear Programming Multiobjective Optimization Network Methods Nonlinear Programming
II. SPACE/C41SR	Operational Contribution of Space Systems C41SR Operations Research & Intelligence Information Warfare Electronic Warfare & Countermeasures Unmanned Systems Military Environmental Factors	
III. JOINT WARFARE	Land & Expeditionary Warfare Littoral Warfare/Regional Sea Control Power Projection, Planning, & Execution Air Combat Analysis & Combat ID Special Ops/Operations other than War Joint Campaign Analysis	**Probabilistic Operations Research** Decision Analysis Markov Processes Reliability Simulation Stochastic Processes Queuing Theory
IV. RESOURCES	Mobility & Transport of Forces Logistics, Reliability, & Maintainability Manpower & Personnel	
V. READINESS & TRAINING	Readiness Analytical Support to Training & Mission Rehearsal Battlefield Performance, Casualty Sustainment, & Medical Planning	**Applied Statistics** Categorical Data Analysis Forecasting/Time Series Multivariate Analysis Neural Networks Nonparametric Statistics Pattern Recognition Response Surface Methodology
VI. ACQUISITION	Measures of Effectiveness Test & Evaluation Analysis of Alternatives Cost Analysis Decision Analysis	
VI. ADVANCES IN MILITARY OR	Modeling, Simulation, & Gaming Revolution in Military Affairs (Long Range/Strategic Planning) Computing Advances in Military OR	**Others** Advanced Computing Advanced Distributed Systems (DIS) Cost Analysis Wargaming

Length of Papers

Submissions will normally range from 10–30 pages (double spaced, 12 pitch, including illustrations). Exceptions will be made for applications articles submitted with a senior decision-maker letter signed by the Secretary of Defense.

Format

The following format will be used for dividing the paper into sections and subsections:

TITLE OF SECTIONS

The major sections of the paper will be capitalized and be in bold type.

Title of Subsections

If required major sections may be divided into subsections. Each subsection title will be bold type and be Title Case.

Title Subsection of a Subsection

If required subsections sections may be divided into subsections. Each subsection title will be Title Case. Bold type will not be used.

Paper Electronic Submission with Figures, Graphs and Charts

After the article is accepted for publication, an electronic version of the manuscript must be submitted in Microsoft Word or WordPerfect. For each figure, graph, and chart, please include a camera-ready copy on a separate page. The figures, graphs, and tables should be of sufficient size for the reproduced letters and numbers to be legible. Each illustration must have a caption and a number.

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Authors should put mathematical and symbolic expressions in Microsoft Word or WordPerfect equations. Lengthy expressions should be avoided.

Footnotes

We do not use footnotes. Parenthetical material may be incorporated into a notes section at the end of the text, before the acknowledgment and references sections. Notes are designated by a superscript letter at the end of the sentence.

Acknowledgments

If used, this section will appear before the references.

References

References should appear at the end of the paper. The references should be unnumbered and listed in alphabetical order by the name of the first author. Please use the following format:

For journal references, give the author, year of publication, title, journal name, volume, number, and pages—for example:

Harvey, R.G., Bauer, K.W., and Litko, J.R. 1996. Constrained System Optimization and Capability Based Analysis, Military Operations Research, Vol 2, No 4, 5–19.

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Morse, P.M., and G.E. Kimball. 1951. Methods of Operations Research. John Wiley, 44–65.

For references to working papers or dissertations cite the author, title, type of document, department, university, and location, for example:

Rosenwein, M. 1986. Design and Application of Solution Methodologies to Optimize Problems in Transportation Logistics. Ph.D. Dissertation. Department of Decision Sciences, University of Pennsylvania, Philadelphia.

Appendixes

If used, this section will appear after the reference.

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